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Disposal of Radium-Barium Sulfate Sludge from a Water Treatment Plant in Midland, South Dakota

Fred C. Hart Associates, Inc.
Denver, CO

Prepared for

Environmental Protection Agency
Denver, CO

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EPA

DISPOSAL OF RADIUM-BARIUM SULFATE SLUDGE FROM A WATER TREATMENT PLANT IN MIDLAND, SOUTH DAKOTA

A TECHNICAL ASSISTANCE PROGRAM REPORT

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16. ABSTRACT

The town of Midland, South Dakota has levels of radium-226 in its groundwater drinking water supply which exceed EPA drinking water standards. A newly-designed treatment plant will use barium chloride to precipitate out the radium. As a result, a radium-barium sulfate sludge will be produced.

The initial task of this report is to determine the degree of radioactivity of the sludge and to investigate the appropriate EPA, NRC and DOT guidelines which regulate the handling and disposal of this low-level radioactive waste. Hazards both to workers and intruders are assessed. The quantity and quality of the sludge are consequently projected and alternative disposal methods evaluated. Packaging and shipment to a licensed radioactive waste disposal site, co-disposal with uranium mill tailings, disposal at a state-operated site, and land disposal at the treatment plant are considered as alternatives. Various immobilization techniques, including bitumenization, polymeric solidification and concrete encapsulation are also investigated.

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ENVIRONMENTAL PROTECTION AGENCY REGION VIII

Public Law 94-580 - October 21, 1976

Technical assistance by personnel teams. 42 USC 6913

RESOURCE RECOVERY AND CONSERVATION PANELS

SEC. 2003. The Administrator shall provide teams of personnel, including Federal, State, and local employees or contractors (hereinafter referred to as "Resource Conservation and Recovery Panels") to provide States and local governments upon request with technical assistance on solid waste management, resource recovery, and resource conservation. Such teams shall include technical, marketing, financial, and institutional specialists, and the services of such teams shall be provided without charge to States or local governments.

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Project Officer: William Rothenmeyer

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CHAPTER 1

INTRODUCTION

The State of South Dakota has at least fourteen small towns that have naturally occurring radium in their drinking water source. In several cases the concentration of radium represents radioactivity levels which exceed EPA drinking water standards. This public health risk poses a dilemma. Removal of radium from the water to acceptable levels will result in a radium sludge which will be radioactive. This also is a potential public health issue, as this radioactive sludge will be stored and may be transported for ultimate disposal.

Minute traces of radioactivity are normally found in all drinking water. For groundwater sources, the concentration and composition of these radioactive constituents varies widely depending on the radiochemical composition of the soil and rock strata through which the water has passed. Some of these radionuclides are alpha-emitters which tend to concentrate in bones. Of these, radium-226 and its daughters and the daughters of radium-228 probably have the greatest potential for producing radiation doses of some consequence to man. The ingestion of radium from contaminated water supplies has been linked to increased human fatalities due to lung and bone cancer, osteitis, skin damage and blood disease (Sax, 1979).

Throughout the Midwest, there are areas where groundwater concentrations of radium-226 and radium-228 approach 150 pCi/liter, well in excess of the EPA drinking water standard of 5 pCi/liter. (Note: A Curie (Ci) is a unit of radioactivity, $1pCi = 10^{-12}$ Ci).

Various techniques are currently in use or under study for removal of radium-226 from industrial and municipal water supplies. One of these methods is the precipitation of radium-barium sulfate through the addition of barium chloride. This precipitate, or sludge, is a low-level radioactive waste and must be immobilized and disposed of properly to minimize the potential public health hazard.

The City of Midland, in Haakon County, South Dakota, (See Figure 1) is one of the small towns in the state with high levels of radium-226 in its water supply. The water treatment and distribution system in Midland serves a population of 270 and is derived from a free-flowing artesian well drilled in the Madison Formation, a Mississippian limestone. This source yields water that is contaminated with naturally-occurring radium-226 at a concentration of 15 pCi/liter, three times the EPA drinking water standard. Furthermore, the source water is highly mineralized and has an ambient water temperature of 152°F. As a result of these properties, Midland's water treatment and distribution system had fallen victim to severe corrosion, which reduced operating capacity by two-thirds. In 1978, the Midland Town Board contracted with a consultant to reconstruct the system and devise appropriate treatment methods for contaminants, including sulfate (SO_4^{-2}), total dissolved solids and hardness ($CaCO_3$), as well as radionuclides.

In October, 1980, the consultant ran pilot plant tests to study the effectiveness of treatment methodologies. These included water temperature adjustment, aeration and sodium hydroxide addition to control corrosion, treatment basins to reduce the solids content, and the addition of barium chloride to induce co-precipitation of radium and barium from the influent.

Several alternate methods of radium removal had been considered prior to the pilot plant test. These included reverse osmosis, ion exchange, lime-soda, lime and barium chloride treatments. The barium chloride process was chosen for the pilot plant study because of lower construction and maintenance costs in addition to the efficiency of radium removal. Previous research conducted by the South Dakota School of Mines and Technology for the town of Philip, South Dakota demonstrated that barium chloride reduced the radium-226 concentration in that water supply from 150 to 1 pCi/l. Futhermore, residual barium in the water remained below the EPA drinking water quality standards of 1 mg/l. This latter result is important in that acute ingestion of barium can have a toxic effect on the heart, blood vessels, and nerves (Sorg, 1980, pp.411-412). The Bill Smith Mine in Douglas, Wyoming, operated by Kerr-McGee, has also used the barium chloride process effectively. Radium-contaminated water from uranium processing there has been treated so efficiently that the mine received the 1980 Clean Water award from the Izaac Walton League.

FIGURE 1

DEWEY
ZIEBACH
MEAD
MISSOURI RIVER
CHEYENNE RIVER
STANLEY
HAAKON
PIERRE
BAD RIVER
PHILIP
MIDLAND
PENNINGTON
JONES
JACKSON
N
0
75 MILES

The pilot plant tests for Midland used a 4 mg/l concentration of barium chloride mixed with the influent. The water was then passed through three settling chambers in series to settle the precipitate. Residual barium and radium precipitate was removed by filtration and precipitated out in a settling tank. After precipitation, the radium-226 concentration in the effluent was 0.5 pCi/l, which, while higher than the background concentration of 0.01 to 0.1 pCi/l occurring in the natural environment, is significantly below the EPA drinking water standard of 5 pCi/l.

Based on the success of the pilot plant study, the consultant recommended a final plant design, as shown in Figure 2. The plant will have a design flow rate of 57,600 gallons per day. From the well, water will first enter cooling ponds to reduce the ambient temperature. The water will then pass into a static mixer, where 5 mg/l of barium chloride will be added, and parallel flow streams will then be split into two concrete-lined treatment basins. These will provide for an approximate 30-hour average detention time and are expected to achieve a 95+ percent removal efficiency of the radium/barium sulfate precipitate. The water will then be routed back for pH adjustment, and will be detained in two other treatment basins. From there, the stream will pass through two dual media sand filters where the remaining radium/barium sulfate precipitate will be removed. These filters will be backwashed into a sludge pond which will be constructed with a reinforced concrete floor and concrete paved slopes up to one-foot above normal water level. The accumulated sludge from the basin and sludge ponds will be collected via underdrains into an 11,000 cubic-foot sludge pond to await ultimate disposal. This pond will be constructed with a reinforced concrete floor and clay-lined side slopes.

The City of Midland has requested EPA to provide technical assistance under the TA Panels to study the sludge disposal problem resulting from the proposed water treatment plant. Fred C. Hart Associates, Inc. is conducting this study to provide this specific assistance and to provide a framework whereby other communities in similar circumstances can address the options available to them.

A low-level radioactive sludge from a publicly-owned and operated water treatment plant presents a regulatory uncertainty. The sludge is not covered by either Nuclear Regulatory Commission (NRC) or EPA hazardous or radioactive waste

CONCEPTUAL SCHEMATIC
MIDLAND WATER TREATMENT PLANT

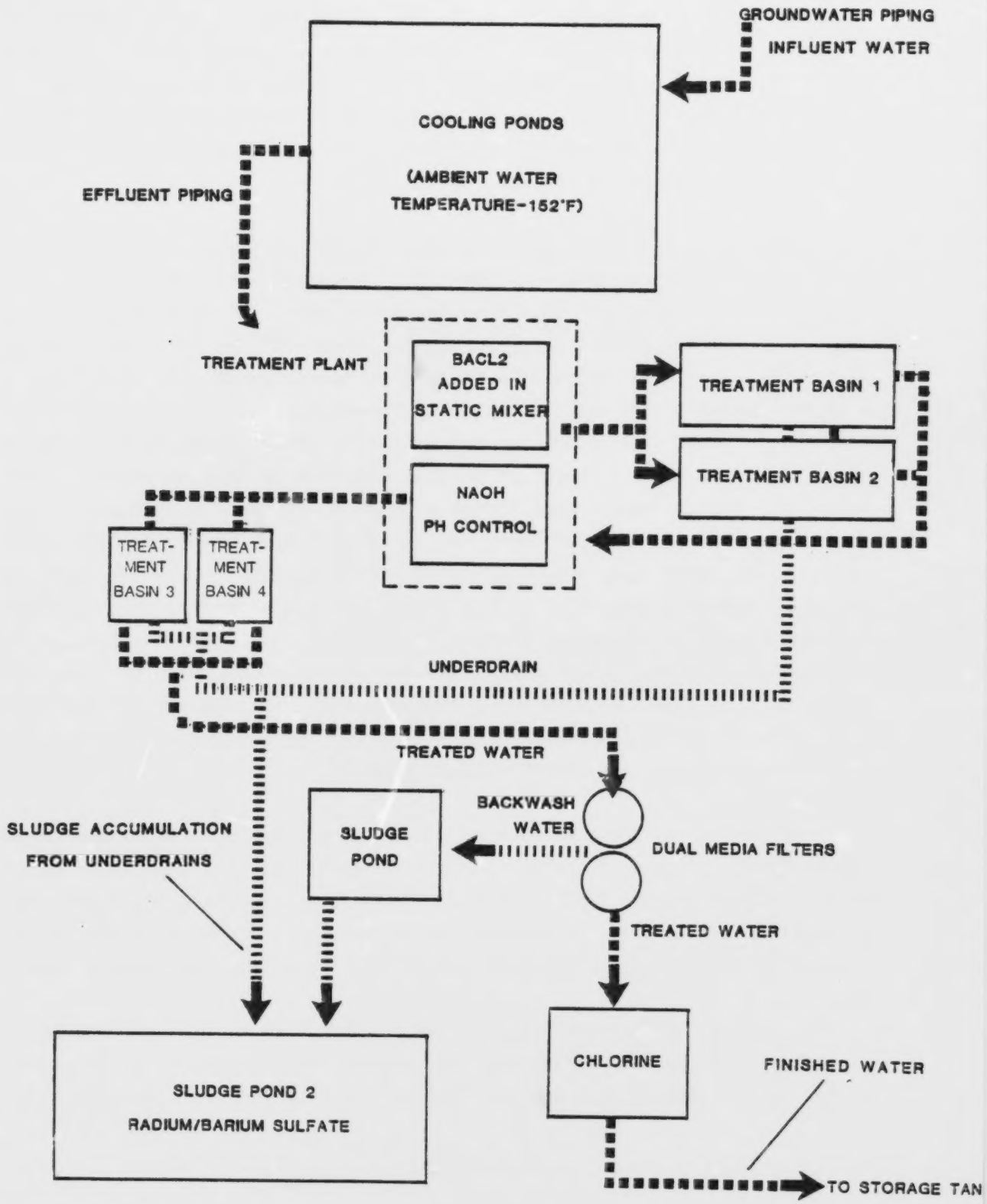

FIGURE 2

regulations. At present, the regulatory responsibility lies with the State which also lacks guidelines for this specific situation. Chapter 2 of this report presents a discussion of the regulatory issues that potentially could affect the analysis of disposal options.

Disposal options for the sludge are almost entirely controlled by the following four characteristics: 1) quantity of sludge generated on an annual basis; 2) the concentration of barium and other chemicals in the sludge; 3) radium-226 concentration (specific activity) in the sludge and 4) radon gas flux from the sludge. Radon-222 gas, a decay product of radium-226, is chemically inert. When inhaled, however, radon daughters, which are solids, precipitate in the lungs and induce lung cancer. Thus, any analysis of disposal options must consider possible gaseous migration of radioactive products.

Chapter 3 reviews the information gathered during the pilot plant study, and completes a mass balance analysis for radium and barium in the sludge. These analyses lead to the description of disposal options presented in Chapter 4. Chapter 5 summarizes the data and proposes recommendations.

The appendices present supporting data for the waste form options (primarily sludge immobilization techniques) that may be used for disposal of low-level radioactive wastes. Some of these options may have greater applicability to other communities than for Midland. The appendices also present detailed calculations supporting the analysis, a discussion on the health effects of radioactive waste, and a copy of the form required by the State of South Dakota to license a facility generating radioactive waste.

CHAPTER 2

REGULATORY RESPONSIBILITY

As municipalities with radium contaminated water supplies upgrade their water treatment processes, it is foreseeable that the resultant precipitants may become a regulatory dilemma unless authority is clearly designated at the outset. The radium/barium sulfate sludge potentially generated at Midland is a test case as far as regulatory authority is concerned. The two principal constituents of this material, radium and barium, would usually cause it to come under the aegis of three federal agencies: the Nuclear Regulatory Commission, the Environmental Protection Agency and the Department of Transportation. As explained in the following discussion, however, none of these agencies directly controls this type of sludge because of its specific activity and its origin. Ultimately, regulatory authority is held by the state of South Dakota, which, like most states, has promulgated legislation to control radioactive materials.

Nuclear Regulatory Commission

The Nuclear Regulatory Commission is typically the initial contact with federal control of radioactive waste. This agency is responsible for regulating the licensing, generation, containment and disposal of radioactive material under Title 10 of the Code of Federal Regulations (CFR). The NRC does not, however, regulate radium waste unless it is associated with the nuclear fuel cycle. In fact, the agency's single involvement with radium is derived from Public Law 95-604, The Uranium Mill Tailings Radiation Control Act of 1978, which deals only with uranium mill tailings. Of interest to Midland and other municipalities facing similar problems are current NRC developments in technical requirements for the long-term land disposal of low-level radioactive waste. These have been published in the Draft Environmental Impact Statement on 10 CFR Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste". These requirements are expected to be finalized by January, 1983 and will be designed to provide: 1) protection for the inadvertent intruder; 2) assurance of long-term stability to eliminate the need for long-term maintenance after operations cease; 3) protection of public health and safety (and the environment) over the long-term; and 4) assurance of safety during the short-term operational phase

(USNRC, 1981, page 23). Although these standards will only be applicable to radioactive material coming under the purview of NRC, the technical criteria from this rule may also serve as guidelines for disposal of non-NRC regulated low-level radioactive waste. Furthermore since the options discussed in Chapter 4 include transport of the waste to NRC-licensed disposal sites the waste will be required to conform to NRC regulations that apply to those sites.

Environmental Protection Agency

The Environmental Protection Agency is mandated to protect human health and the environment, therefore, it has an interest in any potentially hazardous waste. For two reasons, however, the radium/barium sulfate sludge generated at Midland's treatment plant is currently deferred from direct EPA regulation. Principally, EPA authority is designed to prevent duplication of NRC control over radioactive waste. As a consequence, the current extent of EPA involvement with radioactive material is through PL 95-604 and 40 CFR Part 192, which define shared responsibilities for uranium mill tailings with NRC and the Department of Energy; and through 40 CFR Part 190 which sets limitations for releases of radiation from nuclear fuel cycle facilities. EPA also has standards setting authority for wastes covered by the Atomic Energy Act, and may in the future issue regulations under the Resource Conservation and Recovery Act to control low-level radioactive wastes. However, once a waste is at a NRC licensed facility, EPA's jurisdiction is preempted by NRC.

A radioactive material also comes under the purview of EPA if its other constituents are hazardous. Some barium compounds and others which may be associated with the Midland treatment plant sludge are potentially hazardous. EPA, through the Resource Conservation and Recovery Act, has designated as hazardous wastes those that exhibit characteristics of ignitability, corrosivity,reactivity or toxicity.* The first three characteristics are not applicable to this type of treatment plant sludge. The sludge might be toxic, but 40

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* EPA may in the future issue regulations, under Resource Conservation Recovery Act to control low-level radioactive wastes.

CFR Part 261.24 states that the barium concentration must exceed 100 mg/l to qualify a waste as hazardous. The nature of the proposed radium-removal process for Midland is such that barium concentrations would be much lower than 100 mg/l.

Department of Transportation

The Department of Transportation regulates the shipment of any radioactive and/or hazardous material. DOT is a possible regulating authority if any radioactive sludge is shipped off-site for ultimate disposal. It is the only federal agency that will exercise direct authority over the treatment plant sludge after it is designated a radioactive waste by the state. Actually, DOT has created its own definition of radioactive material in 49 CFR Part 173.389 (E), ruling that the estimated specific activity must be greater than 2,000 picocuries per gram (pCi/g). Sludge from the radium removal process will probably not be characterized by specific activities over 1,200 pCi/g, as shown in Chapter 3 of this report. Therefore, DOT does not retain direct regulatory control over the material until another agency designates it as radioactive by their standards. In such cases, shipment must be conducted according to 49 CFR Part 173.392 which requires that waste be packaged in leak-proof containers with acceptable levels of external radiation, and transported in appropriately marked vehicles.

South Dakota

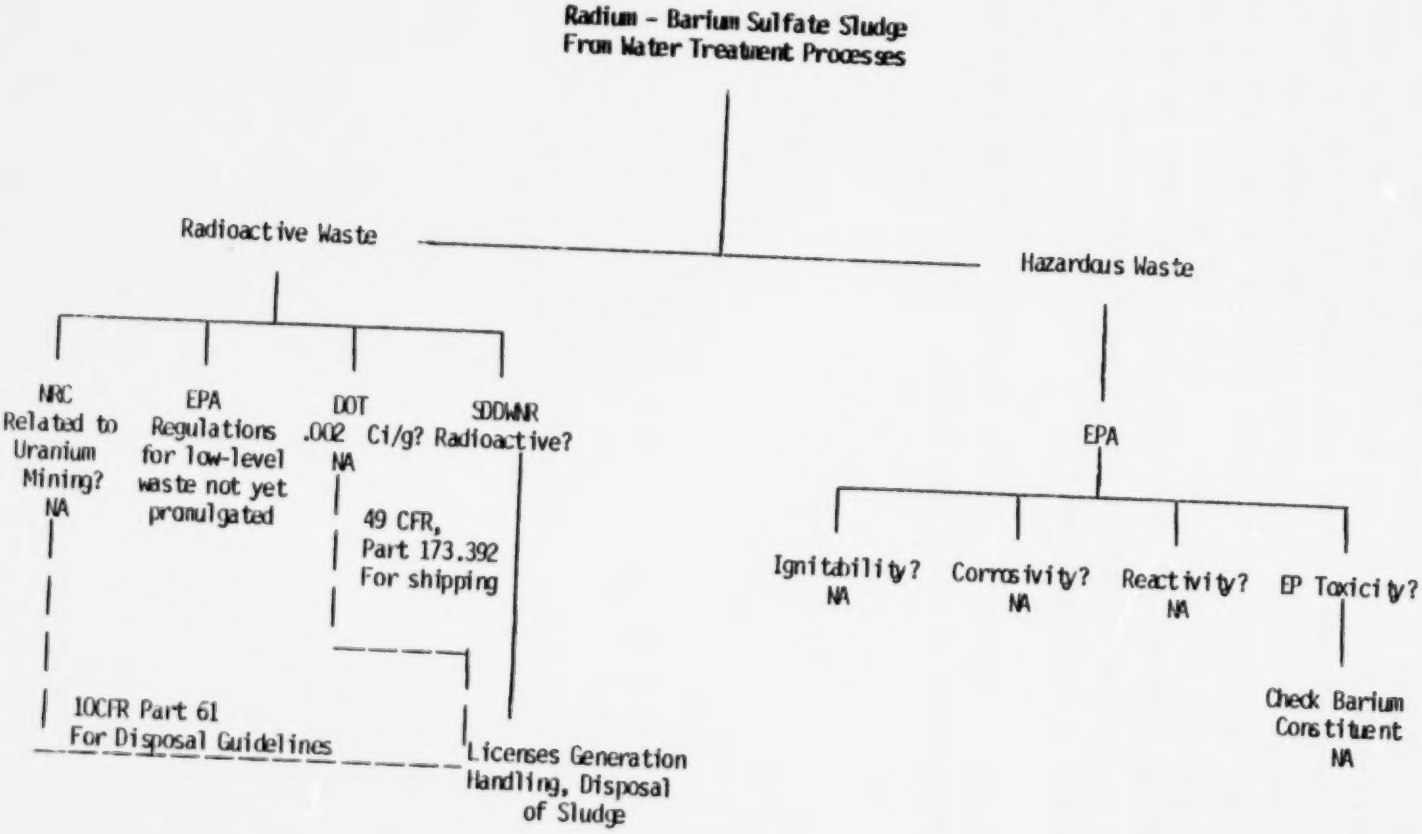
State legislation may currently provide the most consistent regulation of low-level radioactive waste. South Dakota has passed the Radiation and Uranium Resources Exposure Control Act (34-21-1) and regulations have been promulgated (Chapter 44:03:01) which give the Department of Water and Natural Resources the authority to license radioactive material. The regulations require that any facility that will generate a radioactive material, including sludge from water treatment processes, must obtain a license prior to start-up. This license must be renewed annually and will also be required for disposal of the sludge. The license application form is presented in Appendix D of this report. Currently, disposal of high-level radioactive waste is not allowed within state boundaries without legislative consent. Unfortunately, the regulations do not provide a clear distinction between high and low-level radioactive waste. There is also a

lack of regulatory precedence for disposal of waste from radium-contaminated water supplies. The licensing procedure requires that descriptions be submitted for facilities and equipment, radiation protection and disposal procedures. Given the existing regulatory uncertainty in South Dakota and at the federal level, it is imperative that the licensee work closely with the Department of Water and Natural Resources during the early phases of sludge generation, containment and disposal. This will require that the licensee submit test samples of the sludge demonstrating its actual specific activity and chemical constituents. Furthermore, NRC guidelines for waste disposal and DOT shipping requirements should be discussed with the South Dakota Department of Water and Natural Resources as the disposal options presented in Chapter 4 were developed predicated on approval by regulatory agencies.

Figure 3 depicts in summary fashion the regulatory considerations appropriate to the Midland radium-barium sulfate sludge.

FIGURE 3

REGULATORY CONTROL


Radium - Barium Sulfate Sludge From Water Treatment Processes
Radioactive Waste
Hazardous Waste
NRC Related to Uranium Mining? NA
EPA Regulations for low-level waste not yet promulgated
DOT .002 Ci/g? NA
SDDWNR Radioactive?
49 CFR, Part 173.392 For shipping
10CFR Part 61 For Disposal Guidelines
Licenses Generation Handling, Disposal of Sludge
EPA
Ignitability? NA
Corrosivity? NA
Reactivity? NA
EP Toxicity?
Check Barium Constituent NA

NA - not applicable
NRC - Nuclear Regulatory Commission
EPA - Environmental Protection Agency
DOT - Department of Transportation
SDDWNR - South Dakota Department of Water and Natural Resources

CHAPTER 3

MIDLAND WATER TREATMENT PROCESS

Background

The town of Midland, South Dakota, has a difficult water supply problem. In this area the surficial aquifers are generally small and localized. These aquifers are considered inadequate for development of a municipal water system serving the town. Therefore, the municipal system is served by a 3,300-foot well into the Madison formation. The water from this artesian well has a temperature of 152° F., is highly corrosive and has naturally occurring radium-226 in excess of drinking water standards. The corrosiveness of the water has greatly diminished the storage capacity of the town's storage tank. Asbestos-cement pipe is used for the transmission and distribution system in order to minimize the impacts of the corrosive water. This pipe is more susceptible to breaks as a result of minor soil movement. Thus, the reliability of Midland's drinking water system is poor.

Midland retained Banner Associates to design a water treatment plant and distribution system. Accordingly, the plant has been designed in order to meet EPA drinking water standards and to achieve a non-corrosive water supply.

The initial study by Banner (1979) focused on traditional treatment operations for cooling, pH control, and carbon dioxide removal. The issue of radium-226 removal has been more complex. The initial study focused on several treatment alternatives for radium removal. These included: lime and lime-soda softening, ion exchange softening and reverse osmosis. This study recognized that while both ion exchange and reverse osmosis treatment methods could meet the water quality criteria, they would be very expensive. Co-precipitation of the radium with barium sulfate, through the addition of barium chloride, was considered as a potentially attractive lower cost alternative. This treatment alternative, however, has been used primarily in the removal of radium from industrial process waters. Since the ingestion of barium has potential adverse health effects, a concentration of 1 mg/l has been established for drinking water. For industrial process applications, there is no concern with any

residual barium in the water. With barium chloride treatment of public water supplies, there is concern that residual barium levels would exceed drinking water standards.

After the initial study, a more intensive examination was completed on the barium chloride treatment alternative (Banner, 1980). This study indicated that promising results have been obtained in Wyoming and in applying the barium chloride treatment to public water supplies in South Dakota. On the basis of these results, it was decided to conduct a pilot plant study of the barium chloride treatment process on Midland water.

The results of the pilot plant study were very encouraging. The concentrations of radium-226 were reduced from 10 to 15 pCi/l in the raw water to 1 pCi/l and lower in the finished water. Of equal importance, barium concentrations in the finished water remained below 1 mg/l (Banner, 1981). Additionally, the treatment process to control corrosion by cooling, carbon dioxide removal, and sodium hydroxide addition were equally promising. The remaining major issue is with the radium sludge--its handling and disposal.

Sludge Disposal

In designing the sludge disposal system, there are three major concerns:

- physical and chemical characteristics of the sludge;
- the radioactivity of the radium-226 and its decay products;
- the potential of radon gas emissions.

Physical and Chemical Characteristics of the Sludge. While the pilot plant tests have been very promising, they provide limited information regarding the quantity and quality of the sludge. This limits a complete assessment of sludge disposal alternatives and forces a worst case analysis so that, given the various uncertainties, protection of public health is assured.

The sludge from the Midland water treatment plant is very complex. In addition to radium and barium sulfate it can be expected that the sludge will contain other precipitates removed from the highly mineralized water. The pilot plant did not generate sufficient quantities of sludge to completely characterize all the potential precipitates, although a significant amount of iron hydroxide is expected, and has been included in the sludge volume calculations which are presented in Appendix A. The most significant constituent other than radium is, of course, barium. The barium concentration in the sludge is variable according to quantities of unknown solids in the raw water supply. As shown in Appendix A, leachable barium in the sludge should not exceed 5 mg/l, which is below the standard of 100 mg/l given in 40 CFR Part 261.24 for EP Toxicity characteristics. In any case, the controlling hazard factor in sludge disposal will be the radioactivity of the material. It is important, however, that samples of the generated sludge be tested for toxic as well as radioactive characteristics. Care must be taken during disposal procedures to ensure that barium or other potential chemical contaminants do not enter a surface or groundwater source in significant quantities.

It is important to understand the nature of the radioactive decay process to place this analysis in perspective. A detailed discussion of the radioactive decay process and its effects on health is presented in Appendix B. A summary is presented below.

Radioactivity

Radioactive decay is the decomposition of one element into another. During the process of decomposition alpha, beta and gamma rays are emitted. It is these rays which pose a potential health problem.

We are continually exposed to radioactive materials naturally present in the environment. They are a health hazard only when the concentration of material is present in significant quantities.

The Midland water treatment process results in concentrating the naturally occurring radium in the groundwater to high quantities in the sludge. The process removes amounts of radium-226 from the groundwater (approximately 15 x 10-12 grams of radium-226 for each liter of water). The removal process

places the radium in a sludge where the radium-226 is concentrated at one part of radium-226 per one million parts of sludge. It is the concentration of radium-226 in the sludge that determines the appropriate disposal alternative from this perspective alone.

Radon. Radon gas is a decay product of Radium-226. Radon presents a design and operational concern for the water treatment plant as well as for sludge disposal.

The general health issues regarding radon are discussed in Appendix B. In sludge disposal, protection from radon gas is achieved by blocking the migration path for the gas through covering, immobilizing, or encasing the waste. Barriers should be able to resist wind and water erosion and human, animal, and plant intrusion. The exact design choice depends upon the specific waste, its activity, and the site.

When radon is entrained in water it will not migrate above the surface of the water in significant amounts. The sludge drying ponds should therefore be covered with a layer of water to prevent the release of radon and to prevent dried sludge from being windblown. It is important that high levels of radon do not remain in the treated water, since it would be released in homes when the water is aerated, such as in showers. If water at the treatment plant is aerated, it is important that it be done outside of a building or in a well ventilated building.

Before conclusions can be made regarding the Midland sludge disposal problem, initial estimates of the quantity and quality of sludge must be made.

Water Treatment Process Analysis

The proposed water treatment system for Midland (see Figure 1) provides for a design flow of 57,600 gallons per day and for carbon dioxide removal by aeration, barium chloride addition, co-precipitation of the radium with barium sulfate in detention ponds with approximately 30 hours detention time, sodium hydroxide addition, additional sedimentation in a smaller pond with a four hour detention time, filtration, disinfection, storage and distribution. All sludge

generated in the treatment system will contain some radium-226. Additionally the material removed during filtration will also contain radium-226. The sludges, which are typically 5 percent solids, and the backwash from the filters containing the material removed during filtration, will be pumped periodically to an evaporation pond. The sludge disposal issue consists of what to do with the sludge from the evaporation pond and when to do it.

As a worst case analysis for the quantity and quality of the sludge the concentration of radium-226 in the water is estimated high, and it is all assumed to be removed (the pilot plant results achieved a removal efficiency of 96 percent). Additionally the amount of sludge (the dilution for the radium-226) is estimated by considering a 96 percent removal efficiency for the barium (according to the pilot plant results are almost 90 percent). Based on these two assumptions and the concentration of barium chloride added, the dry weight, volume, and activity of the sludge can be calculated. This is the most concentrated form of the radium removed from the water and thus its most active state. In reality, the sludge should never be completely dry. A dry radioactive sludge presents a serious health hazard since it will resemble a powder and can be transported by wind and inhaled. In reality the sludge that will be generated and handled will be a mixture of water and solids. Thus, for this analysis, several possible sludge solids-water content ratios are presented.

The calculation for the weight, volume and specific activity of the sludge on a dry basis and at 5, 10 and 20 percent solids by weight are presented in Appendix A and summarized in Table 1. The volume of the sludge is important to note from a materials handling perspective, but it must be remembered that this volume is based on an arbitrary assumption of annual sludge handling. If the sludge were handled every six months the volume of sludge would change but the activity per mass of sludge would be the same.

Since other towns face problems similar to Midland's, analyses were also completed for various levels of radium-226 in the influent water, keeping the other conditions constant. The results are shown in Table 1. Increased radium-226 in water means increased radium-226 concentration in the sludge. The volume of sludge, under the same assumptions, is constant. This obviously is an over-simplification. As the level of radium-226 increases it can be expected

TABLE 1

SLUDGE CHARACTERISTICS

Barium Chloride Co-Precipitation of Ra-226

57,600 gpd

5 mg/l $Ba Cl_2$

Specific Activity at Various
Ra-226 Concentrations in
Influent Water (pCi/l)

Volume at Various Solids Ratios	15*	50	100	150
Dry - 224 l	1,250 pCi/g	4,176 pCi/g	8,350 pCi/g	12,526 pCi/g
20% Solids - 2,872	250	835	1,670	2,508
10% Solids - 7,181	125	417	835	1,254
5% Solids - 16,441	63	208	417	627

* Midland's raw water radium concentration.

that the amount of barium chloride added to the water will also increase, and thus the resultant barium sulfate sludge will increase. The level of barium chloride required to achieve a certain removal efficiency for a given water cannot be determined without additional pilot studies. Thus the analyses for influent concentrations of radium-226 greater than 15pCi/l are conservative for calculating the specific activity of the sludge but underestimate the materials handling problems since the required concentration of barium chloride and the resultant volume of the sludge is underestimated. The maximum specific activity for the Midland sludge under dry conditions is 1,250 pCi/g.

There have been several simplifying assumptions made to allow the calculation of the activity of the sludge, along with a consistent attempt to make these assumptions conservative. There has been one assumption which will underestimate the total activity of the sludge.

Radium-226 is a daughter product of radioactive decay that begins with uranium-238. In uranium ore, over milennia, an equilibrium has been established. Each of these radioactive elements contributes to the total activity. In the Midland case it is assumed that none of the precursors or products of radium-226 are present in the raw water. This simplifying assumption can only be verified by a complete chemical analysis of the raw water.

Radium-226 will decay to radon-222 which is an inert gas. Radon like any gas migrates relatively easily. Once the activity (concentration) of radium has been determined the radon flux in the sludge can be calculated to determine if any steps should be taken to attenuate the radon.

Given the maximum radium activity in the Midland sludge the radon flux was calculated to be 4,015 picocuries per meter squared per second (pCi/m^2-sec), well above the design standard of $2_pCi/m^2$-sec for uranium mill tailings (NUREG-0706, September, 1980, v.1, p. 17.).

CHAPTER 4

DISPOSAL OPTIONS

The analysis indicates that in its most concentrated form, the Midland sludge will approach or exceed most regulatory standards used to define similar types of radioactive materials. At a specific activity of 1,250 pCi/g, the sludge almost meets the DOT definition of a radioactive waste (2,000 pCi/g). Furthermore, when comparing this sludge with uranium mill tailings, it is apparent that the sludge is as radioactive as the material for which PL 95-604 was intended to control, even though those regulatory obligations are not directly applicable to non-uranium related material. For example, proposed EPA regulations require clean up of open land when the average radium concentration attributable to tailings exceeds 5 pCi/g outside the boundaries of mill tailings disposal sites. This level is five to ten times the average radium concentration in U.S. soil. For 23 inactive mill tailings sites the average Radium-226 levels are reported to be 579 pCi/g. Thus, in it's most concentrated dry form, the Midland sludge has an activity exceeding that from uranium mill tailings and much greater than the EPA standard for clean up of tailings.

The radon flux is also a significant problem. For the uncovered dry sludge at a thickness of at least 3 meters (referred to in Appendix A as infinite thickness) radon emanation approaches 4,015 pCi/m^2-sec. This radon flux exceeds the natural background level for U.S. soils of .5 pCi/m^2-sec and the design standard of 2 pCi/m^2-sec set for uranium mill tailings.

These two analyses are worst case conditions since they consider the sludge in its dry or most concentrated form. The mitigating factor for both specific activity and radon flux is that the sludge will never be totally concentrated in its dry form unless the sludge undergoes thermal treatment to reduce the moisture content to zero. Even if that should occur, the calculations have not included the contribution of other minor constituents to the sludge that will further dilute the material and reduce both specific activity and radon emanation. The anticipated scenario is one which keeps the sludge at 5 percent

solids in the pond (63 pCi/g specific activity and 0.21 pCi/m^2-sec radon flux). During the disposal phase, the sludge will probably be significantly dewatered, but will be diluted with some form of solidifying agent.

The amount of sludge produced by the Midland treatment plant is very small compared to uranium mill tailings and reactor waste, but equipment has been developed to efficiently handle a wide range of radioactive waste quantities. Therefore, an appropriate method for Midland's particular problem must be chosen. The sludge will be generated at a rate of 224 liters (7.9 cubic feet) at 100 percent solids per year, and 16,441 liters (580 cubic feet) at 5 per cent solids. (Although transforming the sludge to 100 per cent solids is very difficult technically and prohibitively expensive, this analysis presents the 100 per cent solids sludge as a worst case basis.) The sludge can be left in the treatment plant sludge pond for several years before it becomes necessary to dispose of it in order to maintain the settling efficiency of the pond. Volume reduction of the sludge can be accomplished by mechanical dewatering or by segmenting the pond to allow for solar evaporation. Although disposal could occur within any time frame, it will be more efficient to consolidate several years accumulation. The variables in this decision are: 1) the capacity of dewatering and immobilization equipment and, 2) economies of scale for transporting large versus small quantities of waste. To derive an estimate of the quantity of sludge that might approach optimum disposal efficiency, it is necessary to consider the size of the sludge pond, the quantity of sludge that settles in the pond and the amount that will require disposal. For the purposes of this analysis two scenarios were developed: 1) disposing of the sludge once each year and 2) disposing of the sludge once every ten years. These scenarios bracket the extreme cases in that once per year disposal might be unwarranted whereas once each ten years might be too long a period to allow the sludge to remain in the pond.

1) At one year accumulation
   - -settling pond = 11,000 cubic feet (bottom dimensions 13 x 58 feet, 2 to 1 side slopes)
   - -sludge at five per cent solids = 580 cubic feet
   - -depth of sludge in pond = 0.7 feet
   - -sludge at 30 percent solids for disposal = 57 cubic feet

2) At ten year accumulation
   -settling pond = 11,000 cubic feet
   -sludge at five per cent solids = 5,800 cubic feet
   -depth of sludge in pond = 4 feet
   -sludge at 30 percent solids for disposal = 570 cubic feet

As various disposal options are examined, both these scenarios will be considered. Volume estimates for the dewatered sludge for disposal will change as transport and packaging costs are evaluated because solidifying or immobilizing agents will generally increase those volumes.

Disposal of low-level radioactive waste is not a simple matter and this is especially true for small quantities of material such as that generated at Midland. The options considered include some that may not be viable two years hence. Conversely, there are options that will not become feasible for several years. Much of this uncertainty has developed as a result of the Low-Level Radioactive Waste Policy Act of 1980. In this legislation, the federal government adopted a formal policy to the effect that each state was responsible for providing disposal capacity for commercial low-level radioactive waste generated within its borders. To carry out this policy, the act affirmed the rights of the states to enter into regional compacts and mandated the establishment of disposal sites by 1986. As a consequence, the currently-available disposal sites may not be the sites available in a few years. Adding to the uncertainty, the Nuclear Regulatory Commission is in the process of formalizing regulations for the land disposal of low-level radioactive waste in 10 CFR 61. These regulations may not be promulgated until 1983 at which time it can be expected that requirements for waste disposal will again be altered.

There are basically four options to consider for Midland's sludge disposal: 1) disposal at Midland; 2) disposal at a central site in South Dakota; 3) disposal at an out-of-state site and 4) disposal with tailings at a uranium mill. Specific costs have been developed for these options wherever possible, but generic descriptions have been favored in order to retain the usefulness of this study for municipalities which face similar problems.

Disposal at Midland

A review of the alternatives makes disposal near the treatment plant seem very appealing. There are no transportation costs to consider, no fees or surcharges from a site owner/operator and no NRC licensing requirements. The initiation of any low-level radioactive waste site, even a very small, restricted one, is a serious undertaking. This is illustrated by the fact that there are only six off-site disposal facilities in the United States, three of which are now closed. Therefore, the South Dakota Department of Water and Natural Resources must carefully weigh the following considerations before allowing any disposal site to be constructed at Midland.

The disposal plan must effectively provide for three objectives: 1) protection of the public and occupationally exposed workers 2) long-term protection of the environment and 3) protection for the inadvertent intruder. All these objectives are interdependent and the effectiveness of the overall plan is a function of their achievement.

Protection of the Public and Occupationally Exposed Workers. While in the sludge pond at the treatment plant, the Midland sludge does not pose a significant threat. The gamma exposure five feet above the pond is 1.34×10^{-4} Roentgens per hour (R/hour) after ten years of sludge accumulation. Furthermore, a worst-case scenario assuming that the sludge is a point source yields an exposure rate of only 1.05×10^{-3} R/hr (see Appendix A for exposure calculations). Gamma radiation is more penetrating than alpha or beta particles and requires more shielding. Therefore, it is a significant type of radiation regarding potential health hazards. The radon flux, at five per cent solids, is only 0.2 pCi/m^2-sec which is the approximate background flux from soils in the United States. The sludge is not a health hazard in this form, especially since it will be isolated from the public via a fence. Based on actual conditions of the Midland sludge, posting should not be required since a radiation area is defined as one with exposure rates as 2×10^{-3} R/hr or above. Furthermore annual time of worker exposure is extremely low (approximately 30 hours). Significant increases in the doses of gamma and radon emanation will, however, occur as the result of dewatering the sludge and removing it from the sludge pond for disposal. Therefore, these basic safety measures should be followed in order to ensure minimum exposure to personnel in accordance with 10 CFR Part 20 during disposal procedures:

Personnel. All personnel engaged in the handling/disposal operations involving the radium sludge must be familiar with the hazards associated with the sludge and the measures to be taken to reduce those hazards to an absolute minimum. The operating plan at the Midland water treatment plant calls for only one operator to be in attendance at the plant for a maximum of 10 hours per week. Only a very small portion of this time will be spent in the vicinity of the sludge pond. Therefore, primary emphasis on monitoring radiation exposure should be directed towards those involved with disposing of the sludge since these workers will have the most sustained, direct contact with the material. It is recommended for this reason that contractors specializing in radioactive waste disposal and equipped to do the work be hired for the disposal phase. These workers should already be operating under radiation safety procedures with film badges and dosimeters as standard job equipment. They will record and maintain dates, times and amounts of exposure and observe established practices for handling/disposal.

Protective Clothing and Equipment. Personnel engaged in the handling or disposal of the radium sludge should wear the following:

- o Protective clothing (coveralls)
- o Boots
- o Gloves
- o Headgear
- o Breathing mask/apparatus
- o Goggles

Equipment. Equipment to be used during disposal operations should be inspected for serviceability prior to commencement of disposal operations. Only licensed operators should be allowed to operate equipment.

Operations. The following should be instituted as standard operating procedures:

- o No food should be allowed or consumed in the vicinity of the sludge disposal area.

- o Persons with open cuts or sores should not be allowed to engage in disposal operations.
- o Operations should be conducted with wind blowing away from disposal personnel (up-wind).
- o Personnel should shower immediately after completion of operations.
- o Only those personnel engaged in the disposal operations should be permitted in the area.

One of the primary reasons for immobilizing the sludge is to prevent dispersion of the radionuclides during subsequent phases of the disposal procedure. There are several immobilization alternatives, as summarized in Table 2 and detailed in Appendix C. The appropriate alternative for Midland should be chosen on the basis of the longevity and integrity of the waste form and the capital and operating costs.

Waste Form Integrity. The waste form must be one that will not be damaged by radiation. Radiation damage to an encapsulized form will manifest itself by either physical or chemical changes, which result from the material absorbing the energy and/or particles originating from radioactive decay. The physical changes can include cracking, swelling, loss of tensile/compressive strength, shrinking, and discoloration. Chemical changes can result in gas generation and formation of corrosive substances. The most common radiation damage effects are swelling and gas generation. These occur to a significant degree only after the material has absorbed a certain amount of energy. The point at which a containment material is significantly altered by radiation absorption is referred to as the threshold limit. These are given in Appendix C under "radiation damage level". Those limits which are noted as "unknown but should be extremely high" indicate that the material can absorb at least 100 times the radiation that can be absorbed by glass without significant damage. Even though the specific activity of the sludge from Radium-226 is not extremely high, the total radiation dose to the encapsulating material can still be significant. Furthermore, the additional radiation coming from the Radon-222 daughter products will serve to increase the radiation dosage that must be absorbed by the material.

Waste Form Costs. Costs for immobilization of the sludge will be contingent on the associated processing temperature, complexity of the handling proce-

TABLE 2
SOLIDIFICATION ALTERNATIVES IN ORDER OF PREFERENCE

Immobilization Process	Pro	Con
Cementation	1. Sludge need not be dried. 2. Capital and operating costs are low. 3. Operating simple.	1. Sulfate content may decrease waste loading in cement waste form. 2. Gas generation by radiolysis may be problem.
Chem-Fix	1. Same as cement.	1. Same as cement.
Bitumenization	1. Sludge need not be dried. 2. Sulfate content no problem 3. Capital and operating costs are low to medium.	1. Off-gas and water vapor may need to be treated. 2. Gas generation by radiolysis & bacteria may be problem.
Polymeric Solidification	1. Sludge need not be dried. 2. Sulfate content no problem. 3. Capital + operating costs are low to medium.	1. Elimination of standing water is difficult. 2. Gas generation by radiolysis may be problem.
Calcination	1. Production is lightweight. 2. Gas generation isn't a problem.	1. Sulfur oxides emission would have to be controlled. 2. Leach rate is very high. 3. Continuous processing options produce fine, granular product.
Vitrification-Borosilicate Glass	1. Leach rate is very low. 2. Gas generation isn't a problem.	1. Sludge must be calcined first. 2. Capital + operating costs are high. 3. Listed waste loading couldn't be used since too much alkali earth oxides increases the leach rate significantly.
Vitrification-High Silica Glass	1. Leach rate is very low. 2. Gas generation isn't a problem. 3. Sludge need not be dried.	1. Technology is unproven. 2. All costs are very high. 3. Process involves calcination which means an off-gas treatment system.
Cermet	1. Leach rate is very low. 2. Gas generation isn't a problem. 3. Sludge need not be dried.	1. Technology is unproven. 2. All costs are very high. 3. An off-gas treatment system is required.
Glass Ceramics	1. Gas generation isn't a problem.	1. Technology is unproven. 2. All costs are high. 3. An off-gas treatment system is required.
Basaltic Slag	1. Gas generation isn't a problem. 2. Municipal waste could be used as a fuel/additive source.	1. Technology requires some development. 2. All costs are very high. 3. An off-gas treatment system is required.
Synroc	1. Leach rate is very low. 2. Gas generation isn't a problem.	1. Technology is unproven. 2. All costs are very high. 3. An off-gas treatment system is required.

dure for small quantities of the waste and raw material requirements. Costs will generally escalate with increased processing temperature although high temperature procedures do yield a high integrity waste form. These procedures are also the most expensive and complex and are suited for large quantities of relatively high-level radioactive waste. The basaltic slagging process, for example, was developed for processing large quantities of transuranic wastes (those having an atomic number greater than 92). Vitrification, glass ceramics, cermets and Synrock B have been developed primarily for immobilizing high-level radioactive wastes. Calcination has typically been used for treating large volumes of high-level liquid wastes.

Bitumenization, several methods of cementation, and polymeric solidification have been used extensively on low-level wastes such as the Midland sludge. Immobilization of the sludge can also be inexpensively accomplished by packaging the dewatered sludge in barrels filled with diatomaceous earth. The sludge is first dewatered utilizing a disposal filter; the filter and the dewatered sludge are placed in a 30-gallon drum packed with diatomaceous earth.

The 30-gallon drum is then inserted into a 55-gallon drum which is also packed with earth. The diatomaceous earth provides an absorbent material that would immediately stop the migration of any liquid remaining in the dewatered sludge. This type of immobilization is currently accepted at commercial disposal sites, but it is not an actual solidification process and may not yield the stable waste form provided by the alternatives listed in Table 2.

Table 3 lists unit costs for cementation, bitumenization, polymeric solidification and diatomaceous earth. These are based on disposal of ten years accumulation of Midland sludge. Costs are variable depending primarily on dewatered sludge volume and transportation for equipment and crew. It is apparent that this latter cost could be significantly reduced in each case by consolidating several years accumulation of sludge instead of immobilizing it on an annual basis. It appears that cement, used in a permanently installed facility at the treatment plant, will be the most cost effective immobilization media for providing a stable waste form. Figure 4 is a conceptualization of a trench that would be required to hold 10 years' accumulation of sludge immobilized with cement and packaged in 55-gallon drums. Calculations for this scenario are given in Appendix A.

TABLE 3

COST CONSIDERATIONS FOR
IMMOBILIZATION OF THE MIDLAND SLUDGE[1]

	Capital Investment	Equipment and Crew Transportation	Disposables	Labor
Cement, Permanent Unit	$4,000	---	93 drums[4] @ $150 $13,950	Plant Operation
Cement Mobile Unit	---	$5,000	1 liner holds 100ft^3 @ $4,000 each $24,000	Weekly=$4,000
Chem-Fix	---	Package @ $50 ft^3 $28,500	---	---
Diatomaceous Earth[2]	---	$2,050 (includes labor)	earth = $360 60 drums @ $30 each $1,800	---
Polymeric Solidification[3]	---	Package @ $150ft^3 $85,350	---	---
Bitumenization	---	$10,000	1 liner holds 100ft^3 @ $4,000 each $24,000	$3,000

1 Costs are based on ten year disposal of sludge at 30% solids = 16,100 liters or 570 ft^3. Extrapolated from costs for disposal of one year sludge accumulation - represents 1981 dollars, not adjusted for inflation.

2 Diatomaceous earth results in a sludge at 95 percent solids due to a disposal filter used in the process for dewatering.

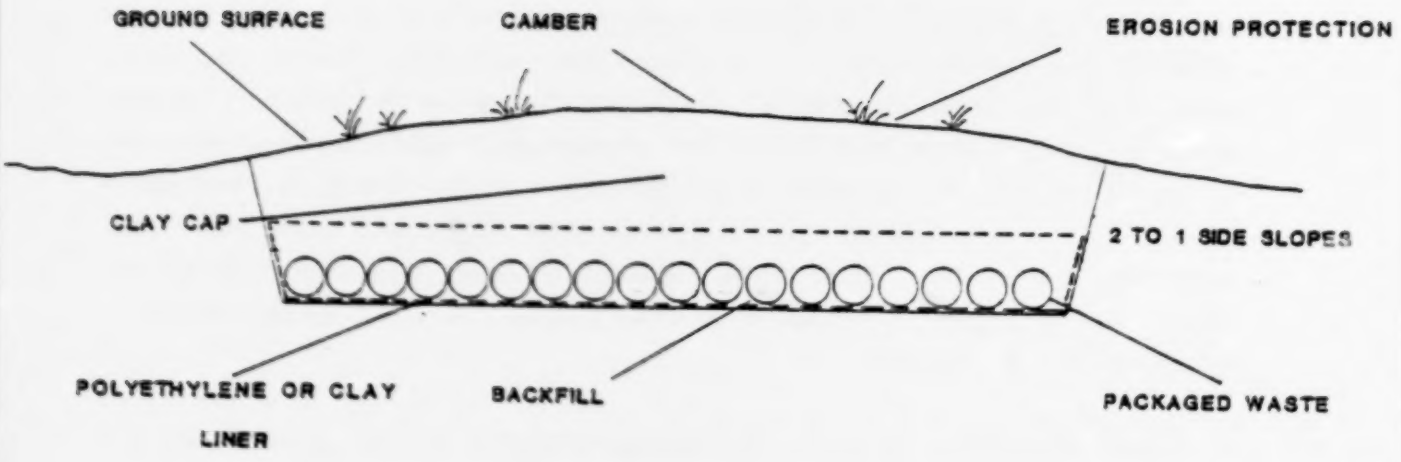
3 Based on costs for vinyl ester styrine media (brand name - Dow Binder). Costs are approximately $150 to $200 per cubic foot; material can be mixed in container.

4 Each drum contains enough reagent to solidify 40-46 gallons (6.15 ft^3), drums are DOT spec. 17H)

FIGURE 4

CONCEPTUALIZATION OF

A WASTE BURIAL TRENCH



NOT TO SCALE
SEE TRENCH DESIGN
APPENDIX A

It should be noted here that the costs in Table 3 are estimates and reflect current market trends. Furthermore, anticipated technological advancements will certainly be introducing new processes for immobilization in the near future. One such product, a high-integrity, rigid, polyethylene container, should be made widely available within the next year. This particular product will provide complete containment of the sludge in a dewatered state without necessitating solidification by an immobilizing medium. Low-level radioactive waste disposal authorities in Hanford, Washington have indicated that preliminary tests of these containers proved satisfactory although each petition for using them to dispose of wastes at Hanford will be considered on a case-by-case basis.

Long-Term Protection of the Environment. An unstable waste form enhances potential groundwater migration of radionuclides, can result in waste decomposition, which may cause differential settlement of the burial trench. Furthermore, an unstable waste form facilitates widespread dispersion of radionuclides if the trench cap is disturbed or eroded. The burial trench is continually subject to adverse impacts associated with water migration, plant and animal intrusion, and erosion. These three factors, described below, make immobilization of the sludge the first and most crucial step toward protecting the public health and the environment.

Water Migration. Potential groundwater migration of the radionuclides is a serious problem since irreparable damage may be done to an aquifer. For that reason, investigation of the hydrologic resources is a major part of any burial site selection. Midland is characterized by deep groundwater sources, but some shallow seepage wells have been drilled in the upper 60 feet of the Pierre Shale, which contains a highly permeable fractured zone. These wells are not widely used due to low yields, but the water source must be protected from any possible migration of radionuclides from a disposal trench. Therefore, if a site is selected, several groundwater monitoring wells should be drilled up and down gradient of the site to determine the presence and movement of groundwater. This data should be used to locate the trench at a sufficient depth above the water table. Impermeable liners in the trench will also restrict water migration through the waste. These can be in the form of clay, bentonite or a high density plastic material such as polyethylene. A cost has been given for a

polyethlene liner in Table 4. A clay liner might also be provided if borings in the Midland site area indicate that the material is accessible and adequately impermeable.

Increased contact with water will eventually accelerate waste decomposition. This increases leaching and ion-exchange rates which exacerbate migration of the radionuclides. Two other causes of increased water contact are improper soil preparation and subsidence over the trench. Soils over and under the trench will affect the waste contact time. Midland is characterized by clay soils in the uplands and more permeable, alluvial soils in the floodplains of the Bad River and Mitchell Creek. The chosen site should be in the uplands area, therefore, it will be characterized by clay-type soils. These will facilitate construction of an impermeable can, while creating poorly-drained conditions under the trench.

An impermeable cap provides some protection against increased water infiltration if the waste decomposes and the surface of the trench subsides. Poorly-drained soils, however, can also lead to "bathtub" conditions created when water entering the trench cannot leave. (Amir, 1981, p. 20). Backfilling the trench with sand should mitigate this effect by allowing the water to move quickly through the waste to the trench bottom where a French drain can direct the flow along one side of the trench into a sump. (NRC DEIS 10 CFR 61, p. F-32). During the life of the water treatment plant, any leachate collected in the sump can be pumped out and placed in the sludge ponds. After the treatment plant closes, collected leachate would be disposed at a licensed low-level radioactive waste disposal site.

Plant and Animal Intrusion. Plants and animals can reduce the integrity of the disposal site through three pathways: 1) radionuclides brought to the surface where they can be dispersed by wind and water; 2) contamination on or within plants and animals that are consumed by humans and 3) disruption of trench design causing increased percolation of rainwater into the trench (NRC, DEIS 10 CFR 61, pages 5-84). At Midland, impacts from plant and animal intrusion can be mitigated by increasing the thickness of the cap material, ensuring that the waste form is solidified and using barriers such as riprap and cobbles or by ensuring that only short rooted plants cover the trench. Frequent inspection and maintenance of the site will also allow early detection of any problem.

TABLE 4

MAJOR COST ITEMS - DISPOSAL AT MIDLAND

TRENCH EXCAVATION - DOZER	$500 - $1,000
HIGH DENSITY POLYETHYLENE LINER	$3,700
60 ml - $0.76 per ft^2 installed/4,854 ft^2 (assume installation entirely surrounding waste)	
SITE STUDIES	Variable
GROUNDWATER WELLS $500 installed - 4 wells	$2,000
SUBTOTAL COSTS	$6,700
SOLIDIFICATION PROCESS (AFTER 10 YEARS)*	
CEMENT - PERMANENT UNIT	$17,950
CEMENT - MOBILE UNIT	$31,760
CHEM - FIX	$28,450
DIATOMACEOUS EARTH	$ 4,210
POLYMERIC SOLIDIFICATION	$85,350
BITUMENIZATION	$35,760

* Total costs for disposal at Midland would range from $10,910 ($6,700 + $4,210) for solidification using diatomaceous earth to $92,050 ($6,700 + $85,350) for solidification utilizing polymers.

Erosion. Erosion of the trench cap will eventually result in an unrestricted dispersion of radionuclides into the environment. Even a gradual reduction in cap thickness over time could significantly increase radon emanation. As shown in Appendix A, a minimum cover of approximately four feet should be maintained over the immobilized Midland sludge to eliminate hazards from radon-222 gas generation.

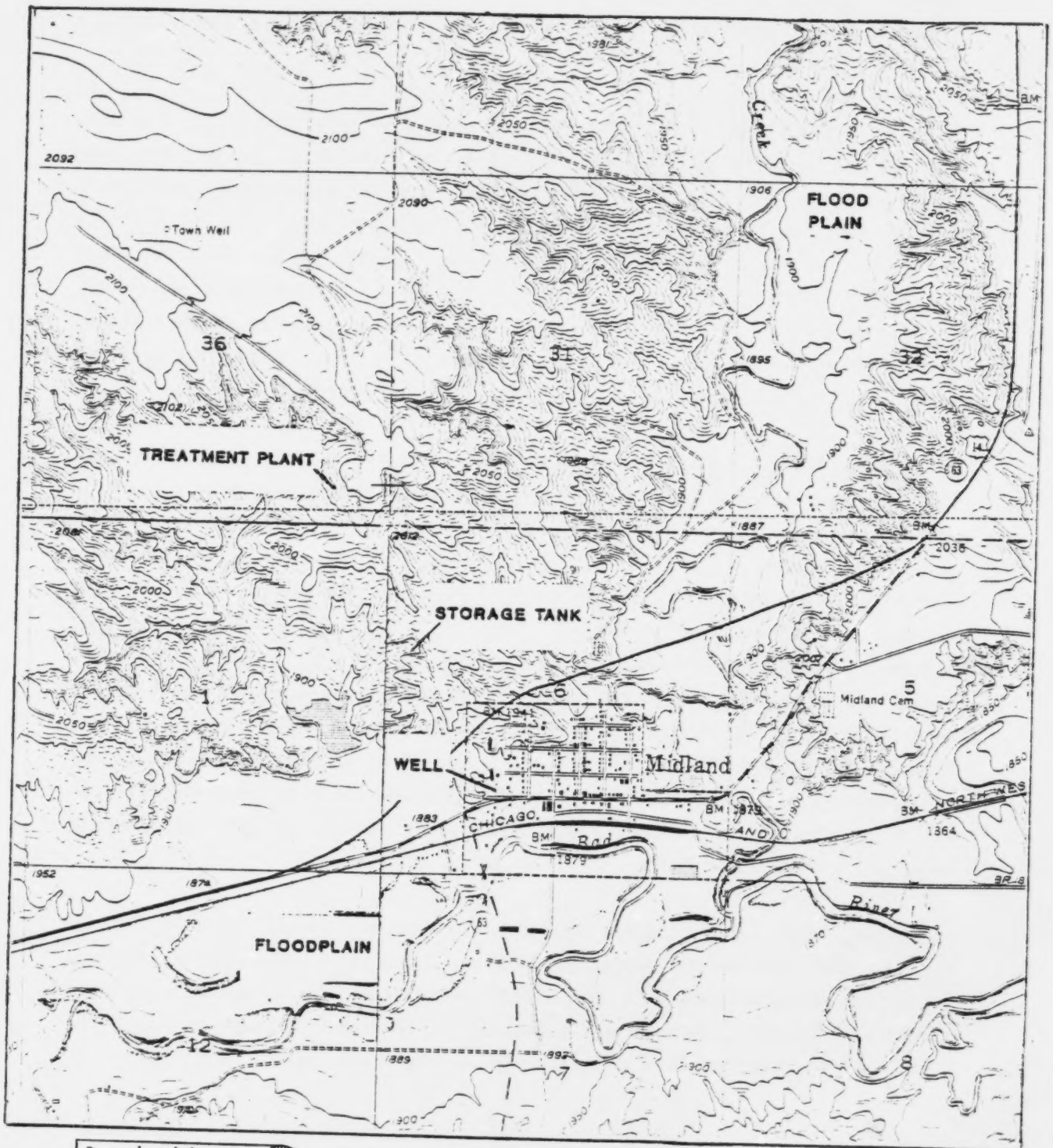
The erosive agents that must be considered when selecting a site are wind and water. Wind damage can be mitigated by introducing a stable vegetative cover or riprap over the cap. Potential water damage can be largely avoided by selecting a site that is elevated above any floodplain area. Figure 5 illustrates the two major floodplains around Midland. Additionally, the site should be located in the upper reaches of any drainage area, in order that there will be no significant amount of overland flow discharging over the disposal site. Surface water control structures such as diversion ditches, can be designed and constructed, if necessary, to divert flow around the trench.

Protection of The Inadvertent Intruder. The previous two objectives, protection of personnel and public during sludge handling and long-term protection of the environment, involve a great deal of pre-planning and design work. These are both, however, objectives that can reasonably be acheived during the lifespan of all parties currently involved with Midland. Perhaps the more difficult problem is planning for protection of the site hundreds of years from now. Radium-226 has a half-life of 1,600 years. The sludge will present a potential public health problem for an estimated 12,000 years. However, NRC has selected only 100 years as the designated time for controls against inadvertent intruders to be in effect (NRC DEIS 10 CFR 61, page 4.1). Unfortunately, scenarios can be envisioned that include future residents of the Midland area unknowingly excavating in the disposal site, growing food over the cap, or drilling domestic water wells into the trench.

Along with the protective measures already mentioned, there are other barriers that can be implemented for intruder control. Institutional controls should be designed that will keep entry restricted, i.e., maintenance of a locked fence, and restricted authorization of personnel allowed to enter the site. Other institutional controls can include benchmarks, duplication of

FIGURE 5

MIDLAND TOPOGRAPHY



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record keeping, continuous control by a governmental agency and covenants recorded in land deeds that will restrict use of the burial site. The location of the site is also a control in that it should be selected in an area that is undesirable for public use within the foreseeable future (NRC DEIS 10 CFR 61 pages 4-41).

It is apparent that the danger from future intrusion could be significantly avoided by restricting the number of radioactive waste sites around the country. It will be much easier to maintain effective control over a few large burial facilities as opposed to many small ones. For that reason, the other options considered for the Midland sludge disposal all involve consolidated sites.

Disposal at A Central Site in South Dakota.

It is foreseeable that the State of South Dakota may consider the construction of a state-owned disposal site if other towns with radium-contaminated drinking water supplies implement a process similar to Midland's. This possibility is very strong if South Dakota does not join one of the regional compacts now being formed in accordance with the Low-Level Radioactive Waste Policy Act of 1980.

Most of the considerations associated with a site at Midland are applicable to any disposal site. The three performance objectives must always be achieved; protection of the public and occupationally exposed workers, long-term protection of the environment and protection of the inadvertent intruder. The magnitude of the entire process will increase with additional waste volume and wastes of higher specific activity. Specific activity will vary according to the level of radium in the drinking water supplies of other towns and the treatment processes utilized to remove the radium.

Should a centralized disposal site be developed in South Dakota, it might be utilized as an immobilization/burial center or simply as a burial site. Immobilizing waste at a central location is desirable in that it eliminates costly equipment transportation to the individual waste generators. It would also ensure that the waste form is reasonably consistent. There are, however, several disadvantages to central immobilization. Primarily, transportation of

bulk liquid radioactive wastes, such as Midland's sludge, is hazardous since any accident causing release of the liquid could result in a difficult waste cleanup problem. For this reason, some packaging and addition of absorbant material should ideally occur prior to transporting the sludge to an immobilization center. Duplicate handling may negate any cost savings realized by central immobilization. Secondly, extreme safety measures would be required at a center that is handling large quantities of diverse waste in order to prevent large-scale spills. Furthermore, each batch of sludge may have to be tested and individually immobilized if the waste chemistry differs significantly.

It is apparent that the preferrable scenario is one in which the state establishes only a burial site. Each waste generator will be responsible for immobilizing the waste for transport and disposal. Table 3 gives approximate costs for immobilization. Transportation costs can be added at a minimum rate of approximately $1.80 per mile.

Disposal at an Out-of-State Site.

There are obvious advantages to utilizing the services of an existing disposal site. The waste generator is not required to contribute large sums to capital development costs. Facility operators are trained and knowledgeable of safety procedures. It can be reasonably assumed that a program of perpetual site maintenance and care is being effectively implemented. Of course, there are also substantial fees for using these sites, and transportation costs to the site can be significant. A variation of the existing out-of-state facility may develop as regional compacts are formed and several states join together to operate one site.

Existing Sites. There are three burial sites in the United States that accept radioactive waste generated by non-Federal facilities. However, the site operated by ChemNuclear in Barnwell, South Carolina does not accept material such as that generated at Midland. The two available sites are both operated by U.S. Ecology, Louisville, Kentucky. The facilities are located in Beatty, Nevada and on the Hanford Reservation near Richland, Washington. Neither of these sites accept waste that is not immobilized. The immobilization methods costed in Table 3 are all currently acceptable methods at Hanford, but the

Beatty facility will require that a Nevada state inspector observe and approve the immobilization procedures. This inspection is reflected in the state surcharges given in Table 5. State surcharges collected at both facilities are used for three programs; perpetual care and maintenance of the site, radioactive waste surveillance and site closure.

The other costs given in Table 5 are disposal and transportation. Disposal costs can be increased based on the R/Hr detected at the waste container surface. Since the Midland sludge is characterized by a low specific activity, it will be charged the base cost. Other charges can be added for non-routine exposure to personnel due to defective waste packaging and for unusual packaging forms. The transportation cost in Table 5 is a rough approximation and will vary significantly depending on the amount of waste and the carrier type (exclusive or non-exclusive). Interstate transport of radioactive material is governed by DOT regulations 49 CFR, Parts 170 through 179. Although the Midland material will be slightly below the DOT definition of radioactive material (2,000 pCi/g), the material will probably be required to meet DOT regulations if South Dakota defines it as a radioactive waste. In any case, the material will exceed DOT packaging requirements because it has to be immobilized in order to be accepted by the disposal facility. The DOT regulations contain detailed shipping requirements for packaging, manifests, and marking (U.S. DOT, 1977).

Future Sites. The lack of existing disposal sites will become increasingly serious as the quantities of generated radioactive waste increase as expected in the near future. The Low-Level Radioactive Waste Policy Act of 1980 was very timely in requiring the states to plan ahead for future waste disposal. A sense of urgency surrounds the formation of interstate compacts because one of the two existing sites, Beatty, Nevada, will not be available for disposal over the long-term. The Hanford site will eventually serve only as the disposal center for the Northwest Interstate Compact, of which South Dakota is not a part. Although some compacts are now being finalized, others are in the very preliminary stages such as the Central States Compact, which tentatively includes Iowa, Nebraska and Kansas. It is conceivable that South Dakota could join a regional compact at any time in the future.

One of the possible choices for South Dakota might be the Rocky Mountain Regional Compact, which potentially includes Colorado, Arizona, New Mexico, and

TABLE 5

DISPOSAL COSTS AT RICHLAND, WASHINGTON AND BEATTY, NEVADA*

	Transportation	Disposal	State Surcharges
Hanford	$1.80 per mile 1,300 miles $2,340	$14.70 per cubic foot 570 cubic feet $8,379	$2.30 per cubic foot 570 cubic feet $1,311
Beatty	$1.80 per mile 1,500 miles $2,700	$15.60 per cubic foot 570 cubic feet $8,892	$0.25 per cubic foot 570 cubic feet $143 $2,200 annual users fee $1,000 annual inspection fee $3.50 per cubic foot inspection charge 570 cubic feet $1,995 Total = $5,338

* As of January 17, 1983

Wyoming. Legislation is now being reviewed by the states involved in that compact, and should be formalized by 1983. Six years after the State of Nevada formally joins a compact, a low-level waste site must be ready to operate because the Beatty site will be closed. It is anticipated that Colorado will be the host state for the regional disposal site since it generates 80 per cent of the region's radioactive waste, although another state may share that responsibility. Therefore, if South Dakota joins the Rocky Mountain Regional Compact, it is not possible to determine how far the waste from Midland will have to be transported, nor is it yet possible to develop immobilization requirements, disposal costs or surcharges . It may be safe to assume, however, that the costs estimated for the existing Hanford and Beatty sites represent minimum costs for disposal at a future compact facility.

Disposal with Tailings at a Uranium Mill.

In the relatively new field of radioactive waste disposal, uncommon methods may often be the most effective. For various reasons, waste disposal with uranium mill tailings is not commonly practiced. Some of these reasons include: 1) potential liability on the part of the mill operator, 2) difficulty of record keeping, 3) reluctance of state government to allow additional wastes to cross state boundaries and 4) NRC license requirements. If these deterrents could be overcome, it is conceivable that the Midland sludge might eventually be disposed in an uranium mill's tailings pond. This, of course, would also depend on the location and waste form requirements.

Deterrents. The reluctance of mill operators to accept other radioactive waste is understandable. The mill does not have an incentive to accept additional material, especially if the isotopes differ from those in the tailings. The Midland sludge , however, is very close to the specific activity of tailings. In fact, some mills use the same barium chloride co-precipitation method to treat their process water. The resultant sludge is disposed with the tailings. There is a chance, therefore, that a mill would accept the Midland sludge since its constituents are compatible with the tailings.

Recordkeeping is very important in the waste disposal process, but a mill generating large quantities of radioactive waste may have some difficulty

dealing with the records of a small, infrequent disposer. The problem could be avoided by recording any outside waste with a third party, such as a state government agency.

It is very possible that a state which hosts a uranium mill might discourage the transport of additional radioactive waste in the state. The state receives no revenues from the products that created that waste and it can be legitimately viewed as a health hazard if not transported and buried properly. Although this particular roadblock may not be overcome in the near future, it is foreseeable that the formalization of regional compacts may result in a satisfactory solution.

The Nuclear Regulatory Commission licenses uranium mill tailings, therefore, the disposal of any other waste with the tailings will require a license amendment. Amendment fees range from $150 to $3,500, depending on the complexity of the change. The fee should be paid by Midland. The possibility of obtaining an amendment is good, since the sludge represents a very small and infrequent quantity and resembles the tailings and process water treatment sludge. Furthermore, this option consolidates waste, as opposed to creating a new waste site. This coincides with NRC policy to localize and centralize the disposal of radioactive wastes. The uranium mill should be located as close as possible to Midland in order to minimize transportation costs. There are several in Wyoming that should still be operating when the sludge is ready to be moved and these might be contacted before disposal is necessary. There is also one mill in South Dakota. This particular mill is located near Edgemont along the Wyoming border in the southwest corner of the state. It was licensed to the Tennessee Valley Authority, but the license has not been renewed and the mill is being decommissioned. A plan for disposal of the tailings is discussed in the final environmental statement related to the decommissioning of the Edgemont Uranium Mill (NUREG-0846, 1982). This mill may not be a feasible long-term disposal option for Midland since decommissioning should be completed in a few years.

Waste Form Requirements. The waste form that is brought to the uranium mill is contingent on the NRC, DOT, and the mill itself. Although NRC licenses the tailings disposal, the requirements that extend to waste brought to Hanford

and Beatty would probably not apply in this case, since without immobilization the sludge is a compatible form with tailings. The DOT will certainly regulate shipping of the material across state lines, but the stringency of waste form and packaging requirements may hinge on South Dakota's definition of the waste. Ideally, the waste should not be immobilized in order that it can be put through the dewatering process with the tailings and pumped into the disposal area. Dumping of a solid form into a pond could damage the installed liner material. If the sludge could be left in a slurry state, pumped into a tank truck and transported to a mill, cost savings could be potentially significant.

CHAPTER 5

RECOMMENDATIONS AND CONCLUSIONS

In considering the disposal options for the Midland sludge, it is important to remember that the task of selecting a specific alternative will not be necessary for several years. The treatment plant will not be operable until 1983, and the sludge ponds are designed to hold approximately ten years accumulation of waste. Obviously, changes will occur in the technology and regulation of radioactive waste disposal during that time. The options considered, however, present relative comparisons that should remain valid. An attempt has also been made to forecast some of the options that will become available in the future.

Based on current information, it is recommended that the sludge be stored in the ponds for several years before removal. The sludge should be kept in a relatively highly liquid form (no more than 20 per cent solids,) in order to reduce the blowing of dryed sludge. Restricted access to the ponds should be maintained. Before any sludge is generated, however, the town of Midland should contact the South Dakota Department of Water and Natural Resources in order to obtain a license for generating and storing radioactive material. The state will require that the sludge be sampled after the treatment plant is operable. These tests will serve to confirm and modify calculations used to predict the volume, chemical constituents, and specific activity of the waste.

As disposal of the sludge becomes imminent, it is recommended that the material be allowed to dry to a slightly higher solids content in order to supplement dewatering that might be necessary for the immobilization process. There are two disposal options that appear to be the most viable: 1) immobilization of the sludge and transport to a compact state site and 2) non-immobilization and transport to a uranium mill. Although both these alternatives depend on future political attitudes and agreements, there is a reasonable chance that they will be the most viable options ten years hence. Furthermore, both of these alternatives exclude the necessity of costly site development and maintenance. By centralizing the disposal of radioactive waste, the potential for future environmental contamination by inadvertent intrusion will be significantly diminished.

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APPENDIX A

DETAILED CALCULATIONS

MIDLAND WATER TREATMENT PLANT SLUDGE ANALYSIS

Sludge Activity and Volume

Assumptions: Design Flow Rate = 40 gpm; 57,600 gpd; 2.18×10^5 l/d

One Year Operation

Influent Water Concentrations:

- Radium-226: 15pCi/l; 1 gram of Ra-226 = 1 Curie; 15×10^{-12} g/l
- Barium: 0.05 mg/l
- Iron: 2.02 mg/l

Effluent Water Concentrations:

- Radium-226: Not significant
- Barium: 1 mg/l
- Iron: <0.02 mg/l

Barium ions added at 5 mg/l in a $BaCl_2$ base

1) Calculate the amount and specific activity of Radium-226 per year accumulating as a sludge.

Radium-226 = Influent Concentration x Total Annual Volume
= 15pCi/l x 2.18×10^5 l/d x 365d/yr
= 1.1935×10^9 pCi/yr or 1.193×10^{-3} Ci/yr
= 1.193×10^{-3} g/yr

2) Estimate the dry weight and volume of the sludge.

Molecular Weight of $BaCl_2$ = 208.25 g/g-mole
Molecular Weight of $BaSO_4$ = 233.4 g/g-mole
Molecular Weight of Ba^{+2} = 137.34 g/g-mole

Molecular Weight of Fe = 55.85 g/g-mole

Molecular Weight of $Fe(OH)_3$ = 106.85 g/g-mole

Specific Gravity of $BaSO_4$ = 4.5 g/cm^3

Specific Gravity of $Fe(OH)_3$ = 3.6 to 4.0 g/cm^3; use 3.8

Sludge Weight = Influent Concentration x Removal Efficiency x Annual Volume x Stoichiometric Ratio

Barium Sulfate Sludge:

$$= 5 \times 10^{-3} g/l \times .96 \times 2.18 \times 10^{5} l/d \times 365\ d/yr \times \frac{233.4}{137.34}$$

$$= .6491 \times 10^{6} g/yr$$

Iron Hydroxide Sludge:

$$= 2 \times 10^{-3} g/l \times 1 \times 2.18 \times 10^{5} l/d \times 365 d/yr \times \frac{106.85}{55.85}$$

$$= .3045 \times 10^{6} g/yr$$

Total Sludge Weight = .6491 + .3045 = $.9536 \times 10^{6} g/yr$

Sludge Volume = Wt. $BaSO_4$ ÷ Sp.G.$BaSO_4$ + Wt. $Fe(OH)_3$ ÷ Sp.G.$Fe(OH)_3$

$$= .6491 \times 10^{6} g/yr \times \frac{1}{4.5 g/10^{-3} l} + .3045 \times 10^{6} g/yr \times \frac{1}{3.8 g/10^{-3} l}$$

= 224 liters per year or 7.9 cubic feet

Leachable Barium in the Sludge

$$\left[Ba^{+2}\right]\left[SO_4^{-2}\right] = K$$

$$BaSO_4 \rightleftharpoons Ba^{+2} + SO_4^{-2}$$

$$\left[Ba^{+2}\right]\left[SO_4^{-2}\right]$$

$X^2 = K$

$X^2 = 1 \times 10^{-10}$ at pH7, temperature 25°C

$X = 1 \times 10^{-5}M = 1 \times 10^{-5}$ gram-mole/l Ba

$$= 137.34 \frac{\text{grams}}{\text{gram-mole}} \times 10^{-5} \frac{\text{gram-moles}}{\text{liter}}$$

$= 1.4$ mg/l

3) Calculate the specific activity of the dry sludge

$$SA = \frac{\text{Total Activity}}{\text{Total Mass}} = \frac{1.193 \times 10^{-3} \text{ Ci/yr}}{.9536 \times 10^{6} \text{ g/yr}}$$

$= 1.25 \times 10^{-9}$ Ci/g = 1,250pCi/g or .00125μ Ci/g

4) Calculate the specific activity of the sludge at various solids ratios.

a) 20 percent solids
Maximum solids ratio for pumping without special equipment

Composite Specific Gravity = (percent water) + (percent $BaSO_4$) + (percent $Fe(OH)_3$)

$$= (0.8 \times 1) + (.14 \times 4.5) + (.06 \times 3.8)$$
$$= 1.65 g/cm^3$$

$$\text{Sludge Weight} = \text{Dry Weight} \times \frac{1}{\text{Dilution Factor}}$$

$$= 0.9536 \times 10^6 g/yr \times \frac{1}{0.2}$$

$$= 4.768 \times 10^6 g/yr$$

$$\text{Sludge Volume} = 4.768 \times 10^6 g/yr \times \frac{1}{1.66 g/10^{-3} l}$$

$$= 2,872 \text{ l/yr or } 102 \text{ cubic feet}$$

$$SA = \frac{1.193 \times 10^{-3} Ci/yr}{4.768 \times 10^6 g/yr} = .250 \times 10^{-9} \text{ Ci/g} = 250 pCi/gm \text{ or } .00025 \mu \text{ Ci/gm}$$

b) 10 percent solids

Composite Specific Gravity = $(0.9 \times 1) + (.068 \times 4.5) + (.032 \times 3.8)$

$$= 1.328 \text{ g/cm}^3$$

$$\text{Sludge Weight} = 0.9536 \times 10^6 g/yr \times \frac{1}{0.1}$$

$$= 9.536 \times 10^6 g/yr$$

$$\text{Sludge Volume} = 9.536 \times 10^6 \text{g/yr} \times \frac{1}{1.328 \text{ g}/10^{-3}\text{l}}$$

$$= 7{,}181 \text{ l/yr or } 254 \text{ cubic feet}$$

$$SA = \frac{1.193 \times 10^{-3} \text{Ci/yr}}{9.536 \times 10^6 \text{g/yr}}$$

$$= .125 \times 10^{-9} \text{Ci/g} = 125 \text{ pCi/g or } .000125 \mu \text{ Ci/g}$$

c) 5 percent Solids

$$\text{Composite Specific Gravity} = (0.95 \times 1) + (.034 \times 4.5) + (0.016 \times 3.8)$$

$$= 1.16 \text{ g/cm}^3$$

$$\text{Sludge Weight} = 0.9536 \times 10^6 \text{g/yr} \times \frac{1}{0.05}$$

$$= 19.07 \times 10^6 \text{g/yr}$$

$$\text{Sludge Volume} = 19.07 \times 10^6 \text{g/yr} \times \frac{1}{1.16 \text{g}/10^{-3}\text{l}}$$

$$= 16{,}441 \text{ l/yr or } 580 \text{ cubic feet}$$

$$SA = \frac{1.193 \times 10^{-3} \text{Ci/yr}}{19.07 \times 10^6 \text{g/yr}}$$

$$= .0625 \times 10^{-9} \text{ Ci/g} = 62.5 \text{ pCi/g or } .0000625 \mu \text{ Ci/g}$$

Radon Emanation

Radon emanation can be estimated for various conditions of the sludge. The emanation, or flux (Jo), is dependent on two significant factors: the moisture content of the sludge and the thickness of the sludge.

The moisture content is the most important characteristic of the bulk diffusion coefficient De/P, which describes the material through which radon gas must pass. Radon is essentially blocked by water, therefore, material having pore spaces filled with moisture will be less permeable to radon. As shown in the calculations below, De/P has been developed for the sludge at a 95 per cent moisture content and at a zero per cent moisture content.

The emanation coeffient is the fraction of radon that escapes the mineral grains and enters the pore space following its production. An E value of 0.2 was chosen as a best estimate for the Midland sludge. This is the value most commonly used for uranium mill tailings (p. 34, NUREG/CR-2340) and it is anticipated that the Midland sludge characteristics will approach those of the tailings (i.e., radium content, particle size and to some degree, moisture content). Figure 5-2 and Table 5-2 of NUREG/CR-1081 illustrate the percent of emanating power demonstrated by various tailings samples. The E coefficient is clustered between 6 and 32 percent and is primarily dependent on the particle size. Since the Midland sludge can be expected to precipitate as a very fine-grained material, it was assumed for comparison's sake that the majority of the material would, when dry, pass through a #200 Tyler sieve. The data presented in Table 5-2 is insufficient to precisely correlate particle size with E values, but the data trends toward a higher E for smaller grain sizes. Without an actual sample of the Midland sludge, it is not possible to assign an exact E value to it, but 0.2 can be defended on the basis that it is within the range of values assigned to known materials having characteristics similiar to that anticipated for the sludge.

1) Calculate the radon flux from sludge containing 95 percent water by weight. (The typical condition of sludge in the treatment plant sludge pond).

$$Jo = (Ra)\rho E (\lambda De/P)^{1/2} F$$

Jo = radon flux

Ra = specific activity of radium-226 at 5 percent solids: 62.5 pCi/g

ρ = composite density (specific gravity) of sludge @ 5 percent solids: 1.16g/cm^3

E = emanation coefficient: 0.2

De/P = bulk diffusion coefficient: 1 x 10^{-6}cm^2/sec (from Table 5-10, NUREG CR-1081; extrapolate from 2.2 x 10^{-6}cm^2/sec at 85.5 percent moisture for mud). This number is an estimate based on the De/P formed with a similiar density, but is conservative since Figure 3.1 NUREG/CR-2340 shows that for every ten percent increase in moisture, the De/P may decrease by an order of magnitude.

λ = decay constant of radium: 2.1 x 10^{-6}/sec

F = conversion factor: 10^4cm^2/m^2

Jo = 62.5 pCi/g x 1.16g/cm^3 x .2 x (2.1 x 10^{-6}/sec x 1 x 10^{-6}cm^2/sec)$^{1/2}$ x 10^4cm^2/m^2

= 2.1 x 10^{-1} pCi/m^2-sec

2) Calculate the radon flux from sludge at 100 percent solids content (the worst case for handling sludge if it is completely dewatered for solidification and packaging).

$Jo = (Ra)\rho E (\lambda De/P)^{1/2} F$

Jo = radon flux

Ra = specific activity of radium-226 at 100 percent solids: 1,250 pCi/g

ρ = composite density (specific gravity) of matrix:

Sludge Weight = $.9536 \times 10^6$ g/yr

Sludge Volume = 224 l/yr

$$\text{Composite Sludge Specific Gravity} = \frac{.9536 \times 10^6 \text{g/yr}}{224 \text{ l/yr}}$$

$= 4.25 \text{ g}/10^{-3}\text{l}$ or 4.25 g/cm^3

De/P = bulk diffusion coefficient: $6.8 \times 10^{-2} \text{cm}^2/\text{sec}$ (from Table 3-1 NUREG CR-2340 value for dry sand)

λ = decay constant of radium: $2.1 \times 10^{-6}/\text{S}$

F = conversion factor: $10^4 \text{cm}^2/\text{m}^2$

$$\text{Jo} = 1{,}250 \text{ pCi/g} \times 4.25 \text{ g/cm}^3 \times .2 \times (2.1 \times 10^{-6}/\text{S} \times 6.8 \times 10^{-2} \text{cm}^2/\text{sec})^{1/2} \times 10^4 \text{cm}^2/\text{m}^2$$

$$= 4{,}015 \text{ pCi/m}^2\text{-sec}$$

It is apparent that the moisture content of the material containing the radon source greatly influences the radon flux. At 95 percent moisture content, the flux is below the standard of 2pCi/m^2-sec set for the allowable radon emanation from uranium mill tailings (NUREG-0706 volume 1, page 17). At zero percent moisture content, the sludge resembles a dry sand and will produce a significantly high radon emanation. In this form, the sludge is vulnerable to being windblown and thereby poses a health hazard to the general public as well as to operators during disposal procedures.

The preceding calculations were based on the assumption that the radium source term in the sludge has an infinite thickness. The following formula has been developed to express radon flux in terms of a finite thickness.

3) Calculate the radon flux for 2,240 liters (2.237m^3) of dry sludge (ten years of accumulation) deposited in a trench described by top dimensions of 4

meters long by 4 meters wide and 2 to 1 side slopes. Bottom dimensions are 3.2 meters long by 3.2 meters wide.

X = tailings thickness: 17cm

$$Jo = R \rho E \left[\lambda De/P\right]^{1/2} \tanh \left[\left(\frac{\lambda P}{De}\right)^{1/2} X\right] F \text{ (from p. 4-5, NUREG/CR-1081)}$$

$$Jo = 1{,}250 \times 4.25 \times .2 \left(2.1 \times 10^{-6} \times 6.8 \times 10^{-2}\right)^{1/2} \times \tanh \left(\left[2.1 \times 10^{-6} \times \frac{1}{6.8 \times 10^{-2}}\right]^{1/2} \times 17\right) \times 10^{4}$$

$$= 1062.5 \times 3.78 \times 10^{-4} \times .0942 \times 10^{4}$$

$$= 378.3 \text{ pCi/m}^2\text{-sec}$$

The thickness of the sludge obviously affects the radon flux and will therefore be a consideration if the sludge is buried in a trench near the treatment plant. The above calculation is, again, a worst-case estimate because the sludge will probably be diluted with a solidifying agent before disposal. In any case, the next step must be to determine the amount of soil cover required to reduce the radon flux to 2 pCi/m^2-sec. The diffusion coefficient for the cover material is very important and is primarily dependent on ambient moisture conditions. There is currently no published data on soils in the Midland area, although it is known that clays characterize the uplands in that region. A methodology for estimating De/P for soil in the Midland area follows:

4) $De/P = .106 \exp(-0.261\ M)$ (from NUREG/CR-2340, page 5)

.106 = diffusion coefficient of radon in air

M = percent weight - of moisture in the porous material

M can be estimated by $3.2\ P_r^{1/2} - 0.03\ E_v + S$ (from NUREG/CR-2340, page 39).

P_r = annual precipitation (in) = 17

E_v = annual lake evaporation (in) = 49 (P_r and E_v taken from SCS charts for the Midland area)

S = soil index

= 2.9 for clay soils

= -1.0 for sandy soils

$M = 3.2 \times 17^{1/2} - 0.03 \times 49 + 2.9$

= 14.63 percent

$De/P = .106 \exp(-0.261 \times 14.63)$

$= 2.33 \times 10^{-3} cm^2/sec$

5) Calculate the soil cover required to reduce the radon flux to 2 pCi/m^2-sec.

$$X_1 = \left(\frac{De_1}{P_1}\right)^{1/2} \times \left[\ln \frac{2\ Jo}{J_1} - \ln\left[\left(1 + \frac{Po}{P_1}\left[\frac{Do/Po}{D_1/P_1}\right]^{1/2}\right) + \right.\right.$$

$$\left(1 - \frac{Po}{P_1}\left[\frac{Do/Po}{D_1/P_1}\right]^{1/2}\right)(J_1/Jo)^2\Bigg]\Bigg]$$ (from eq. 2-44, p. 27, NUREG/CR-2340)

X_1 = cover thickness in cm

D_1/P_1 = diffusion coefficient of soil cover = $2.33 \times 10^{-3} cm^2/sec$

P_1 = .39 (from Table 3.1, NUREG/CR-2340 and Table 5-7, NUREG/CR-1081, porosity for clay soils with De/P comparable to Midland soils. Table 3.1 shows a De/P value for Shirley Basin soil #2 of $4.6 \times 10^{-3} cm^2/sec$, which is the closest value on the table to the Midland soil De/P of $2.33 \times 10^{-3} cm^2/sec$. Additionally, the Shirley Basin soil has a moisture content of 15 percent, and the Midland Basin soil has a comparable moisture content of 14.63 percent. On Table 5-7, the porosity for Shirley Basin soil #2 is 0.39).

Do/Po = diffusion coefficient of dry sludge = $6.8 \times 10^{-2} cm^2/sec$ (from Table 3.1 NUREG/CR-2340 value for dry sand)

Po = .39 (value for dry sand from Table 5-10, NUREG/CR-1081)

Jo = radon flux from sludge at 17cm thickness: 378.3 pCi/m^2-sec

J_1 = desired flux: 2 pCi/m^2-sec

λ = decay constant of radium: $2.1 \times 10^{-6}/sec$

$$X_1 = \left(\frac{2.33 \times 10^{-3}}{2.1 \times 10^{-6}}\right)^{1/2} \times \left[\ln\left(\frac{2 \times 378.3}{2}\right) - \ln\left[\left(1 + \frac{.39}{.39}\right)\right.\right.$$

$$\left[\frac{6.8 \times 10^{-2}}{2.33 \times 10^{-3}}\right]^{1/2}\Bigg) + \left(1 - \frac{.39}{.39}\left[\frac{6.8 \times 10^{-2}}{2.33 \times 10^{-3}}\right]^{1/2}\right)\left(\frac{2}{378.3}\right)^{2}\Bigg]$$

$$= 33.3 \times 5.936 - \ln\left[6.4 \div (-.000123)\right]$$

$$= 136 \text{ cm} = 4.5 \text{ feet of soil cover}$$

This depth of soil cover will vary depending on the ultimate waste form of the sludge and site-specific soil conditions. The following scenario depicts the soil cover that would actually be required for one particular waste form.

6) Calculate the soil cover required to effectively prohibit radon emanation from sludge that has been immobilized with cement (concrete).

Assumptions: Ten Years of Accumulated Sludge

Sludge can be dried to approximately 30 percent solids (slightly low for solar evaporation and slightly high for mechanical dewatering such as vacuum filtration) (Vesilind, 1979)

Composition of Concrete by Weight (Winter, 1972, pages 1-33)

Cement - 10 percent
Water - 15 percent
Sand/sludge mix - 75 percent (sludge should only be a maximum of 50 per cent of this mix, or 37 percent of total weight)

Sludge Weight and Volume at 30 percent solids

Composite Specific Gravity = (percent water) + (percent $BaSO_4$) + (percent $Fe(OH_3)$)

$$= (0.7 \times 1) + (0.2 \times 4.5) + (0.1 \times 3.8)$$

$$= 1.98$$

$$\text{Sludge Weight} = \text{Dry Weight} \times \frac{1}{\text{Dilution Factor}}$$

$$= 0.9536 \times 10^6 \text{g/yr} \times 10 \text{ years} \times \frac{1}{0.3}$$

$$= 3.18 \times 10^7 \text{ grams of sludge per ten years}$$

$$\text{Sludge Volume} = \text{Sludge Weight} \times \frac{1}{\text{Specific Gravity}}$$

$$= 3.18 \times 10^7 \text{g} \times \frac{1}{1.98 \text{ g}/10^{-3}\text{l}}$$

$$= 1.61 \times 10^4 \text{ liters per ten years}$$

Weight of water in Sludge = Sludge Weight - Solids Weight

$$= 3.18 \times 10^7 \text{g} - 0.9536 \times 10^7 \text{g} = 2.226 \times 10^7 \text{g water}$$

Components of Immobilized Sludge

Water is the controlling factor:

$$\text{Total product weight} = \text{Weight of water} \times \frac{1}{\text{Percent Water in Concrete}}$$

$$= 2.226 \times 10^7 g \times \frac{1}{.15}$$

$$= 1.484 \times 10^8 g$$

Cement = 10% by weight = $1.484 \times 10^7 g$

specific gravity cement = $2.3 g/10^{-3} l$

$$\text{volume cement} = 1.484 \times 10^7 g \times \frac{1}{2.3 g/10^{-3} l}$$

$$= 6.452 \times 10^3 \text{ liters}$$

Water = 15 percent by weight = $2.226 \times 10^7 g$

specific gravity water = $1 g/10^{-3} l$

$$\text{volume water} = 2.226 \times 10^7 g \times \frac{1}{1 g/10^{-3} l}$$

$$= 2.226 \times 10^4 \text{ liters}$$

$$\text{Solids} = 9.536 \times 10^6 g \times \frac{1}{1.484 \times 10^8 g} = 6.44 \text{ percent by weight}$$

specific gravity of solids = 4.25 g/10^{-3}l

$$\text{volume solids} = 9.536 \times 10^{6}\text{g} \times \frac{1}{4.25\text{g}/10^{-3}\text{l}}$$

$$= 2.244 \times 10^{3} \text{ liters}$$

Sand = remainder of concrete composition

= 68.6 percent by weight = 1.018×10^{8}g

specific gravity of sand = 2.65 g/10^{-3}l (quartz)

$$\text{volume sand} = 1.018 \times 10^{8}\text{g} \times \frac{1}{2.65\ \text{g}/10^{-3}\text{l}}$$

$$= 3.842 \times 10^{4} \text{ liters}$$

Total Volume of Immobilized Sludge = 6.938×10^{4} liters

Total Weight of Immobilized Sludge = 1.484×10^{8} grams

$$\text{Specific Activity} = \frac{\text{Ra - 226 accumulation over ten years}}{\text{Weight of Immobilized Sludge}}$$

$$= \frac{1.193 \times 10^{-2}\ \text{Ci}}{1.484 \times 10^{8}\ \text{g}}$$

$$= \frac{8.04 \times 10^{11}\ \text{Ci/g}}{1 \times 10^{-12}\text{Ci/pCi}} = 80\ \text{pCi/g}$$

Radon Emanation from Immobilized Sludge =

$$Jo = R \rho E \left[\lambda \frac{De}{P} \right]^{1/2} \tanh \left[\left(\frac{\lambda P}{De} \right)^{1/2} x \right] F$$

R = 80 pCi/g

ρ = density of concrete

= (0.1 x 2.3) + (0.15 x 1) + (.0644 x 4.25) + 0.686 x 2.65)

= 2.5 g/cm^3

E = 0.2

De = 1.69 x 10^{-5} cm^2/g (cement)

P = porosity of matrix: .05

λ = 2.1 x 10^{-6} /sec

X = 1.6 feet (approximate diameter of a 55-gallon drum); 49cm

$$= 80 \times 2.5 \times 0.2 \left[\frac{2.1 \times 10^{-6} \times 1.69 \times 10^{-5}}{.05} \right]^{1/2} \tanh \left[\left(\frac{2.1 \times 10^{-6} \times .05}{1.69 \times 10^{-5}} \right)^{1/2} 49 \right] 10^4$$

= 40 x 2.66 x 10^{-5} x tanh (3.862) x 10^4

= 1.064 x 10^{-3} x .999 x 10^4

$= 1.063 \times 10^{1}$

$= 11 pCi/m^2 - sec$

Required soil cover over immobilized sludge =

$$X_1 = (D_1/\lambda P_1)^{1/2} \left[\ln (2Jo/J_1) - \ln \left[\left(1 + \frac{Po}{P_1} \right) \left[\frac{Do/Po}{D_1/P_1} \right]^{1/2} \right) + \left(\frac{1-Po}{P_1} \left[\frac{Do/Po}{D_1/P_1} \right]^{1/2} \right) (J_1/Jo)^2 \right] \right]$$

X_1 = cover thickness in cm

$D_1/P_1 = 2.33 \times 10^{-3}$ cm ^{2}/sec for soil (from calculations on page 52)

$P_1 = 0.39$

$Do/Po = 3.4 \times 10^{-4}$ cm ^{2}/sec for cement

$Po = .05$

$Jo = 11$ pCi/m^2-sec

$J_1 = 2$ pCi/m^2-sec

$$= \left[\frac{2.33 \times 10^{-3}}{2.1 \times 10^{-6}}\right]^{1/2} \times \left[\ln\left(\frac{(2 \times 11)}{2}\right) - \ln\left(1 + \frac{.05}{.39}\left[\frac{3.4 \times 10^{-4}}{2.33 \times 10^{-3}}\right]^{1/2}\right)\right.$$

$$\left. + \left(1 - \frac{.05}{.39}\left[\frac{3.4 \times 10^{-4}}{2.33 \times 10^{-3}}\right]^{1/2}\right) (2/11)^2\right]$$

$$= 33.3 \times \left[2.397 - \ln (1.049 + .0314)\right]$$

= 77 cm; 2.5 feet

7) Required Trench Size:

Assumptions: Sludge is packaged in 55-gallon drums:
7.4 ft^3; diameter 1.6 feet, height 3.5 feet
Total immobilized sludge: 2,450 ft^3
Drums required = 331

Design - Trench will hold 18 drums on a side

Width = 18 x 1.6 = 29 feet

Length = 18 x 3.5 = 63 feet

Trench bottom = 29 feet x 63 feet

Side Slopes = 2 to 1

Depth of Immobilized Waste + Radon Barrier = 4.1 feet (this is the minimum depth; additional soil cover could be added for protection from intrusion).

Total material to be excavated:

$$\frac{(29 \times 63) + (45.4 \times 79.4) \times 4.1}{2} = 412 \text{ yds}^3$$

Liner Requirements = Floor Area + Cap Area + Side Area (Using depth of two feet assuming drums will be laid on their sides 1.6 feet in diameter and allowing an arbitrary 0.4 feet of backfill between the drums and the liner to avoid tearing the polyethelene.)

Floor Area = $29 \times 63 = 1{,}827 \text{ ft}^2$

Cap Area (calculated from depth of two feet and 2 to 1 side slopes)

$= 37 \times 71 = 2{,}627 \text{ ft}^2$

$$\text{Side Area (Width of Trench)} = 2\left(\frac{37 + 29}{2} \times 2\right) = 132 \text{ ft}^2$$

$$\text{Side Area (Length of Trench)} = 2\left(\frac{71 + 63}{2} \times 2\right) = 268 \text{ ft}^2$$

Total liner requirement = $4{,}854 \text{ ft}^2$

Worker Exposure

Assuming that the activity is uniformly distributed through the sludge, the following calculations delineate the worker exposure. This exposure rate may be high if the solids settle and the radium remains in the solids.

Parameters:

$$E = \pi \Gamma \frac{Cv}{\mu} (1 - e^{-\mu t}) \ln \frac{R^2 + h^2}{h^2}$$ (Introduction to Health Physics Cember, 1969)

E = exposure rate at distance h from a volume source of radius R

R = Area radius

After ten years of sludge accumulation, the top of the pond will measure 74' x 29' = 2,146 ft^2 or a circle of radius $\simeq$ 26.1 ft or 7.97m

Γ = specific gamma ray constant which is 8.25 $\frac{R\ cm^2}{hrmCi}$

(Rad Health Handbook, page 131)

P_1 = a point 1.5m above surface of pond (2 ft freeboard plus 3 ft to midheight of person = 5 ft = 1.52m)

h = $\therefore$ 1.5m

Cv = activity/volume = μ Ci/cm^3 = 6.25 x 10^{-11} Ci/g sludge·1.16 g $\frac{sludge}{cc}$

= 7.25 x 10^{-11} Ci/cc

or 7.25 x 10^{-8} mCi/cc

t = slab thickness = 4' or 1.22m

μ_l = linear absorption coefficient for sludge (cm^{-1})
the sludge is 95 percent water (assuming it is 100 percent water is conservative)

μ_m for Ra daughter emissions in water (.7 MeV average) is .084 $\frac{cm^2}{g}$ (Rad Health Handbook page 138)

μ_m for highest energy Ra daughter in water (2.2 MeV) is .047 $\frac{cm^2}{g}$

(Rad Health Handbook page 138)

$$\mu_l = \left(\mu_m \frac{cm^2}{g}\right)\left(\rho\ g/cm^3\right) = cm^{-1}$$

$$= (\text{for .7 MeV}),\ .084\ \frac{cm^2}{g} \times \frac{1 g H_2O}{cc} = .084/cm$$

$$= (\text{for 2.2 MeV}),\ .047\ \frac{cm^2}{g} \times 1\ g/cc = .047/cm$$

Hence

$$E = \pi I \frac{C_V}{\mu}\left(1 - e^{-\mu t}\right) \ln \frac{R^2 + h^2}{h^2}$$

- for .7 MeV gamma average

$$E = \pi\ 8.25\ \frac{R cm^2}{hr mCi} \cdot \frac{7.25 \times 10^{-8}\ mCi/cm^3}{.084/cm} \cdot \left(1 - e^{(-.084/cm\ .\ 122\ cm)}\right) - \text{(CONTINUED)}$$

$$/n \left[\frac{(7.97m)^2 + (1.5m)^2}{(1.5m)^2} \right]$$

$= 7.56 \times 10^{-5}$ R/hr or .076 mR/hr
at 5' above the pond for 5 percent solids sludge after 10 years.

- for 2.2 Me V gammas

$$E = \pi\, 8.25 \frac{Rcm^2}{hr\ mCi} \cdot \frac{7.25 \times 10^{-8}\ mCi/cm^3}{.047/cm} \cdot \left(1 - e^{(-.047/cm\ .\ 122\ cm)}\right)$$

$$/n \left[\frac{(7.97m)^2 + (1.5m)^2}{(1.5m)^2} \right]$$

Therefore, the exposure rate = 1.34×10^{-4} R/hr or .134 mR/hr at 5 feet above the pond for 5 percent solids sludge after 10 years.

As an approximation of worker exposure at the Midland water treatment plant, we have made the following conservative assumptions:

1) The sludge is a point source.

2) The total gamma activity of the sludge is 1.193×10^{-2}Ci in the 10th year of operation ("worst-case" condition giving maximum exposure to worker).

3) Radium-226 is the sole gamma contributor.

4) There is no shielding between the pond and the worker.

5) The worker spends approximately 1/2 to 1 hour at 10 feet from the pond every 10 days, or an average of 5 minutes per day.

From the Radiological Health Handbook, the specific gamma ray constant (Γ) from radium-226 is 0.825 R/hr at 1m/Ci. For our source term (1.193×10^{-2}Ci), $= 9.8 \times 10^{-3}$ R/hr at 1 meter (3.28 feet). To calculate the exposure rate at 10 feet, apply the inverse square law; $\text{distance}_1^2 \div \text{distance}_2^2$.

$$9.8 \times 10^{-3} \text{ R/hr} \times \frac{3.28^2}{10^2} = 1.05 \times 10^{-3} \text{ R/hr}$$

at 10 feet, the exposure rate = 1.05×10^{-3} R/hr

According to 10 CFR 20.105, this is a permissible level of radiation for an unrestricted area. Since the amount of time spent by the water treatment plant operator in the vicinity of the pond is so short, he is unlikely to exceed the dose criteria listed in 10 CFR 20.105.

APPENDIX B

RADIATION AND HEALTH*

*Abstracted from USEPA, DEIS for Remedial Action Standards for Inactive Uranium Processing Sites, December, 1980, Chapter 4.

Uranium ore, containing uranium-238, is the parent of the radium in the Midland water treatment sludge. Typically in most situations with radioactive elements when a daughter product of the decay series is present the parent is present in an equilibrium concentration. Uranium-238 decays over billions of years to become lead-206, a stable non-radioactive element. The lengthy decay process passes through a series of intermediate elements called decay products, such as thorium-230 and radon-222; these too are radioactive. Figure B-1 traces the steps in the decay series. Uranium decay over the millions of years since the ore was formed has resulted in an equilibrium with the decay products in Figure B-1. All of these decay products are in the ore through which the Midland water source passes. For present purposes, however, it is assumed that only radium-226, and none of its precursors, is present in the water even though its parents are present in the ore. The limited solubility of these precursor elements makes this a reasonable simplifying assumption.

Thus in the sludge only the decay series of radium-226 is of interest. In this decay series to lead-206, there are three kinds of radiation emitted: alpha rays, beta rays, and gamma rays.

All are forms of ionizing radiation, which break up molecules into electrically charged fragments, or ions. In tissue, ionization can produce harmful cellular changes. At the low radiation levels naturally encountered in the environment we expect the effects of such changes to be detectable only with difficulty. Studies show, however, that people exposed to high doses of radiation have a greater chance of developing cancer. If the ovaries or testes are exposed, moreover, the health or development of future children may be damaged.

No one can predict with precision the increased chance of cancer after exposure to radiation. EPA and other Federal agencies base risk estimates on

URANIUM-238 DECAY SERIES

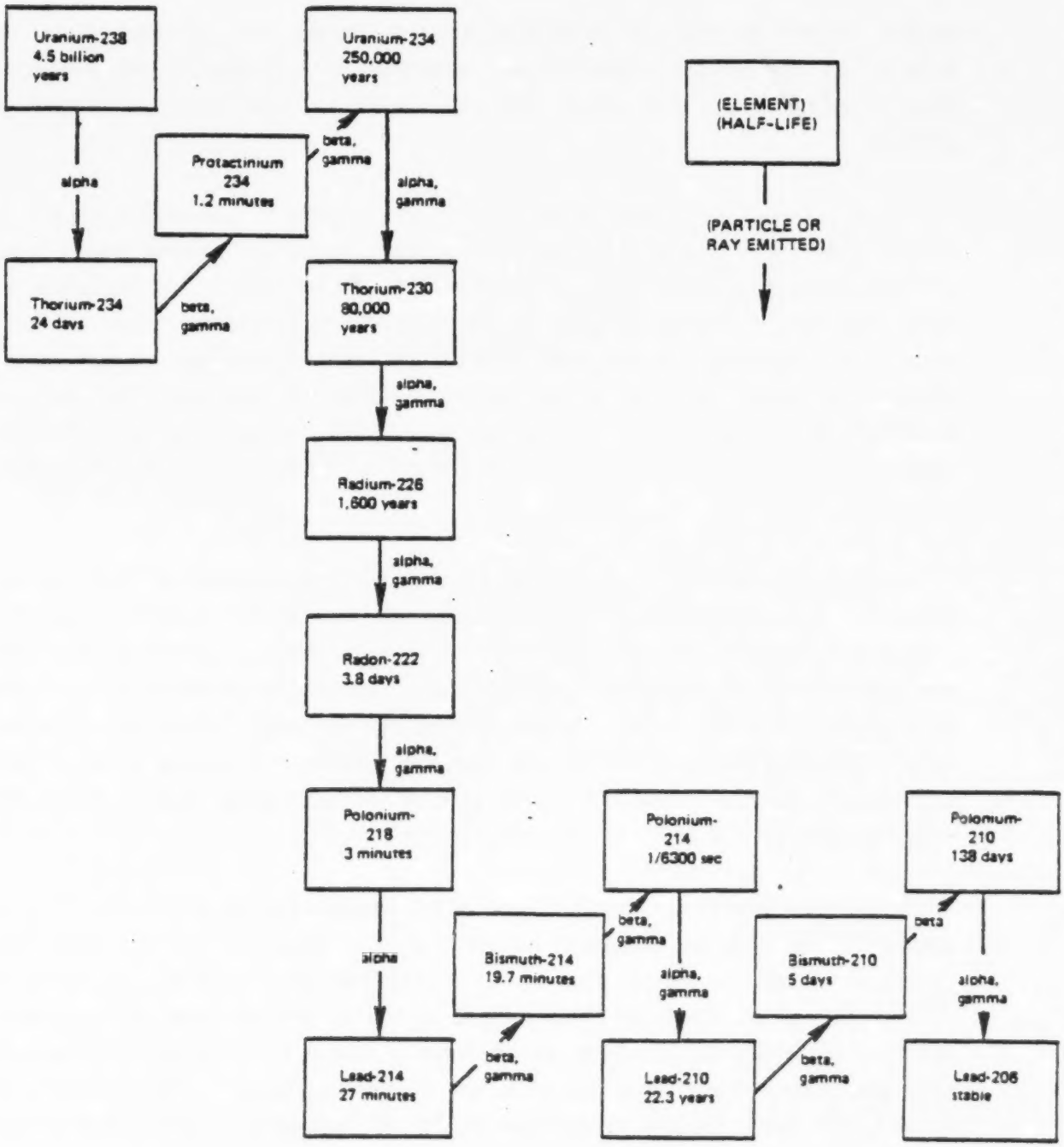

FIGURE B-1

studies of persons exposed at high doses, and assume that at lower doses the effects will be proportionately less. Sometimes this assumption may overestimate or underestimate the actual risk, but it is the best that can be done at present.

Alpha, beta, and gamma radiation are all harmful. The major threat to health from radium daughters comes from breathing air containing radon decay products with short half-lives -- polonium-218, for example -- and exposing the lungs and other internal organs to the alpha radiation these decay products emit. In addition, radioactive material in the sludge may expose people directly to gamma rays, or sludge may be inhaled or ingested. However, the potential harm from inhaling radon decay products is much greater, although radon and its progeny are generally not a health problem unless they are concentrated indoors.

The body's internal organs are exposed to alpha radiation from natural sources. Radium, uranium, thorium, and other radioactive elements naturally present in ordinary rock and soil emit alpha radiation; 1 picocurie of radium per gram of soil is a typical concentration. Outdoor air contains a few tenths of a pCi of radon per liter. Normal eating and breathing introduces these and other radioactive materials into the body, increasing the potential for cancer and genetic changes. Thus any discussion of radioactivity must consider the risk relative to a change from background levels.

The most important decay product in the uranium-238 decay series, for the purpose of defining the longevity of the sludge's radioactivity, is radium-226. Radium in its usual chemical form is relatively insoluble in water, so it can be controlled much as other solid toxic materials with similar chemical characteristics. But radon-222, the radium-226 decay product, is a nonreactive radioactive gas that diffuses from the pile and becomes airborne. The half-life of radon is 3.8 days, so some radon atoms can travel thousands of miles before they decay.

The radon decay series leads through seven principal members before ending with nonradioactive lead-206. The potential health effects of breathing the short half life radioactive decay products immediately following radon are most

important. Members of the decay chain with relatively long half-lives (beginning with lead-210, with a 22-year half-life) are more likely to be ingested than breathed and represent less of a risk.

The principal short half-life products of radon-222 are polonium-218, lead-214, bismuth-214, and polonium-214--decaying, for the most part, in less than an hour. Polonium-218, the first decay product, has a half-life of just over three minutes. This is long enough for most of the electrically charged polonium atoms to attach themselves to microscopic dust particles, less than a millionth of a meter across, in the air. When breathed, such small particles have a good chance of sticking to the moist epithelium lining of the bronchial tubes in the lung. Most of the inhaled material is eventually cleared from the bronchi by mucus, but not quickly enough to keep the bronchial epithelium from being exposed to alpha rays from polonium-218 and polonium-214. These highly ionizing rays pass through several types of lung cells, but the doses they deliver to cells that eventually become cancerous cannot adequately be determined. To do so would require more detailed knowledge than we have of the deposition pattern of the radioactive particles in the lung and the distances from them to the cells. Further, there is even some disagreement about which of the several types of bronchial cells the cancers originate in. Therefore, estimates of lung cancer risk from inhaled radon decay products are based on people's exposure to radon decay products rather than on the dose absorbed in lung tissues.

APPENDIX C

OPTIONS FOR WASTE CONTAINMENT

I. Low Temperature (25 to 250°C) Processes

A. Cementation

Processing steps:

1. Size reduce waste if needed.
2. Determine moisture content of waste.
3. Add the chosen cement* type and required water.
4. Blend in the shipping container or in a separate mixer and pour into the shipping container.
5. Allow to cure.

* Cements can be standard portland, sulfate resistant, high early strength, organic tolerant high alumina, or others.

Operating Temperature and Pressure:	Both ambient
Waste Loading:	To 25 percent by weight
Specific Gravity:	1.7 to 1.9
Bulk Leach Rates in g/cm^2 per day:	10^{-1} to 10^{-6}

The bulk leach rates given have been determined by dividing the weight loss of a sample immersed in room temperature distilled water by the samples's surface area and length of the test. The use of distilled water may or may not represent groundwater. Standard commercial borosilicate glass, such as juice glasses and pickle jars are made out of, has a bulk leach rate of 10^{-5} to 10^{-6} g/cm^2 per day. In general the alkali metals sodium, potassium, etc, leach faster than the alkaline earths, calcium, barium, etc. A comparison of leachate rates does not allow the more stable waste form to be identified.

Radiation Damage Level to Waste Form:	Depends on water content, 10^8-10^{11} rads.
Capital Cost:	Low
Operating Costs (includes raw materials):	Low

General Pluses: Low costs; accepts wet materials; can mix ingredients in the disposal container.

General Minuses: Radiolysis produces hydrogen and oxygen; final waste form is heavier and bulkier.

Variation: Chem-Fix

Processing steps:

1. Size reduce waste if necessary.
2. With sludge pump, recirculate the sludge in the pond with cement, sodium silicate and fly ash.
3. Allow the sludge mixture to harden.
4. When mixture has hardened to a 'diggable' consistency, remove from pond and place in packaging.

See Cementation for other waste form characteristics.

NOTE: Two new processes for cementation have been developed which are called Formed Under Elevated Temperature and Pressure, FUETAP and Cementitious Pelletized Waste Form (CPWF). (FUETAP) uses pressures slightly above ambient, 0.1 MPa (1MPa = milliatmosphere = 0.014 psig), a temperature of 100°C, and a dewatering step at 250°C to lower the water content to 2 percent by weight. Normal cast concrete is 16-20 percent by weight water. FUETAP concrete has greater compressive strength, should have less gas generation by radiolysis, costs more to set-up and operate than cast concrete but has the same waste loading, leach rate, and density.

The CPWF process uses a pressure of 167 MPa (24 psig) applied for several minutes at ambient temperatures to produce a pelletized product 3.8 cm long by 3.8 cm diameter. CPWF has a 2 to 4 percent by weight water content. The CPWF has greater waste loadings (to 55 wt. percent), specific gravity (2.0 to 2.1), a lower leach rate (to 10^{-8} gm/cm^2 per day), a suspected lower radiolysis gas generation than cast concrete but costs more and requires an exact waste particle sizing. The CPWF process could be operated continuously.

B. Bitumenization

Processing Steps:

1. Heat bitumen (asphalt) to 150-230°C.
2. Size reduce waste, if needed.
3. Add waste, either wet or dry, to bitumen.
4. Blend and vent any generated steam.
5. Allow to cool and harden.
6. Both batch and continuous units exist. The batch processing units do not use the disposal container for mixing.

Operating Temperature and Pressure:	150-230°C and ambient.
Waste Loading:	45 to 50 percent by weight
Specific Gravity:	1.0
Bulk Leach Rates in gm/cm^2 per day:	10^{-3} to 10^{-7}.
Radiation Damage Level in Rads:	To 10^8.
Capital Cost:	Low - medium.
Operating Costs (including raw materials)	Low.
General Pluses:	Accepts wet wastes. Product is plastic and elastic. Product is lightweight.
General Minuses:	Nitrates, oxidizing salts cause hardening. Asphalt is flammable. Gas generation occurs by radiolysis and bacteria.

C. Polymeric Solidification

Processing Steps:

1. Size reduce waste if needed
2. Blend organic polymer*, catalyst, and waste.
3. Cure.
4. Batch processes using shipping container or continuous mixer/extender are available

Operating Temperature and Pressure:	25-60°C and ambient.
Waste Loading:	To 33 percent by volume.
Specific Gravity:	Approximately 1.0.
Bulk Leach Rates in gm/cm^2. day:	Unknown.
Radiation Damage Level:	Lower than bitumenized wastes, or less than 10^8 rads.
Capital Cost:	Low.
Operating Costs (including raw materials):	Low-medium.
General Pluses:	Accepts wet wastes. Product is lightweight.
General Minuses:	Polymer microencapsulates waste by curing to form a multi-voided sponge. Elimination of all free standing water difficult. Gas generation may be problem.

* Organic polymers from Todd Research or Dow Chemical or urea-formaldehyde resin can be used.

II. Medium Temperature (650 to 1,300°C) Processes

A. Calcination

Processing Steps:

1. Bring calciner to operating temperature.
2. Add waste and operate calciner at 650°C.
3. Cool calcine and package.
4. This process first dries sludges and liquids and then drives off volatiles such as SO_2 and CO_2 from sulfates and carbonates respectively. Non volatiles and metal oxides are left behind. This process is only suitable for liquids and sludges. Calcination can be batch (pot calciner) or continuous fluidized bed, rotary kiln, spray).

Operating Temperature and Pressure:	650°C and ambient.
Waste Loading:	100 percent.
Specific Gravity:	Varies greatly with processing option.
Bulk Leach Rates in gm/cm^2 per day:	10^{-1} to 1.0.
Radiation Damage Level:	Unknown but very high.
Capital Cost:	High.
Operating Costs: (including raw materials):	Medium, no raw materials required.
General Pluses:	Radiolysis doesn't appear to be any problem. Product is lightweight.
General Minuses:	Volatiles should be treated. Leach rate is very high. Continuous processing options produce fine, granular product.

B. Vitrification - Borosilicate Glass

Processing Steps:

1. Oxidize metals or calcine liquids/sludges.
2. Size reduce waste if needed.
3. Blend waste with glass formers (silicon, aluminum and titanium-oxides) as required to adjust processing temperature.
4. Heat and melt the waste oxide/glass additives either in the disposal container or in a continuous ceramic melter.
5. If continuous melting, form either monoliths or beads/marbles.
6. Cool.
7. Package beads/marbles if required.

Operating Temperature and Pressure:	1,000-1,200°C and ambient.
Waste Loading:	35 percent by weight (uncalcined) to 67 percent by weight (calcined) depending on waste composition.
Specific Gravity:	2.4 to 3.0
Bulk Leach Rates in gm/cm^2 per day:	10^{-4} to 10^{-6}
Radiation Damage Level:	10^9 to 10^{12} Rads
Capital Cost:	High.
Operating Costs (including raw materials):	High.
General Pluses:	Low leach rate. Radiolysis level is high.
General Minuses:	Liquids and sludges must be calcined first. Devitrification (selective crystallization) can occur.

C. Vitrification - High Silica Glass

Processing Steps:

1. Prepare porous high silica glass forms by acid leaching phase-separated alkali-borosilicate glass forms (small sized particles to optimize leaching).
2. Mix the porous forms with a waste slurry.
3. Calcine the waste/porous glass form slurry at 650°C to evaporate the water and volatiles.
4. Load calcined mixture into a large glass "test tube".
5. Heat the loaded tube under a moderate vacuum to 600-900°C to collapse pores in the glass forms.
6. Heat to 900-1,100°C to sinter the glass grains.
7. Continue heating to 1,100-1,300°C to collapse the outer tube around the sintered high silica glass.
8. Seal the top of large tube.
9. Cool.

Operating Temperature and Pressure:	To 1,300°C and moderate vacuum.
Waste Loading:	25-50 percent by weight depending on waste composition.
Specific Gravity:	3.0
Bulk Leach Rate in gm/cm^2 per day:	5×10^{-10}
Radiation Damage Level:	Unknown but probably comparable to other glasses.
Capital Cost:	Very high.
Operating Costs (including raw materials):	Very high.
General Plusses:	Very low leach rate.
General Minuses:	Cost very high. Unproven technology. Involves calciner off-gas treatment systems.

D. Cermet

Processing Steps:

1. Mix the waste slurry, urea, and additives (nickel oxide).
2. Heat the mixture to 150°C to dissolve the wastes and additives and chemically destroy the water.
3. Spray calcine the molten dissolver product at 800°C to produce small, 2 um, particles of mixed oxides.
4. Add a water or wax binder to the calcine.
5. Cold press the powder to about 50 percent of full density.
6. Remove the binder by heating.
7. Use carbon monoxide or hydrogen gas to form metal phases from the reducible oxides.
8. Sinter the pellets at 1,100 to 1,200°C for six hours in an inert atmosphere.
9. Cool.

Operating Temperature and Pressure:	To 1,200°C and unknown (probably greater than 34000 mP_a, 5000 psi).
Waste Loading:	2 to 75 percent by weight depending on amount of reducible metal oxides.
Specific Gravity:	6.0-8.2
Bulk Leach Rate in gm/cm^2 per day:	Less than 10^{-8}.
Radiation Damage Level:	Unknown but should be extremely high.
Capital Cost:	Very high.
Operating Costs (including raw materials):	Very high.
General Pluses:	Very low leach rate.
General Minuses:	Unproven technology. Very high cost.

E. Glass Ceramics

Processing Steps:

1. Follow steps 1 to 4 listed in B. Vitrification - Borosilicate Glass. Additives consist of higher percentages of barium and titanium oxides.
2. Pour melt into a container if continuous operation, hold container at 630°C for three hours for crystal nucleation.
3. Reheat at 800-850°C and hold for 10-15 hours to allow full crystallization.
4. Cool completely.
5. Waste form is now mineral type crystals bound in a glassy matrix

Operating Temperature and Pressure:	Melting at 1,200°C and ambient.
Waste Loading:	20 percent by weight (as oxides)
Specific Gravity:	3.0
Bulk Leach Rate in gm/cm^2 per day:	10^{-4} to 10^{-5}.
Radiation Damage Level:	Significant increase over standard glasses.
Capital Cost:	Very high.
Operating Costs (including raw materials):	Very high.
General Pluses:	Good leach rate.
General Minuses:	Cost very high. Unproven technology.

III. High Temperature (1,400 to 1,500°C) Processes

A. Basaltic Slag

Processing Steps:

1. Mix the coarsely sized (< 3 cm max. dimensions) waste with bark and coal. Bark and coal are added to provide fuel and certain components. Ratio of waste to fuel is highly variable.
2. Feed waste/fuel mixture into reactor.
3. Mixture undergoes, in order, drying, pyrolysis, combustion, and slagging of ash.
4. After burning chamber combusts pyrolyzed gases and generates some slag.
5. Collect slag in glass-type furnace to further homogenate.
6. Cast slag into molds, pour into shipping containers, or water quench to produce a granular frit.
7. Cool and package, if needed.

Operating Temperature and Pressure:	1,400 to 1,500°C and ambient.
Waste Loading:	Approximately 45 percent.
Specific Gravity:	Approximately 3.0
Bulk Leach Rate in gm/cm^2 per day:	10^{-5}.
Radiation Damage Level:	Unknown but should be extremely high.
Capital Cost:	Very high.
Operating Costs (including raw materials):	Very high.
General Pluses:	Good leach rate. Accepts almost any waste type.
General Minuses:	Some development needed. Potential corrosion of refractories. Extensive off-gas system required for volatiles.

B. Synroc

Processing Steps:

1. Calcine liquid or sludge wastes and/or oxidize metals as process only accepts wastes as oxides.
2. Mix the waste oxides with additives, mainly titanium, zirconium, and aluminum oxides.
3. Melt the mixture in an argon - 4 percent hydrogen atmosphere (hot isostatic pressing can also be used).
4. Either perform melting in shipping container, or pour melt into container.
5. Cool slowly (24-72 hours) to allow crystal formation (crystals are minerals - hollandite, zirconolite, and perovskite).

Operating Temperature and Pressure:	1,400°C and ambient.
Waste Loading:	10 percent by weight (as oxides).
Specific Gravity:	4.0
Bulk Leach Rate in gm/cm^2 per day:	10^{-6} to 10^{-7}.
Radiation Damage Level:	Unknown but should be extremely high.
Capital Cost:	Very high.
Operating Costs (including raw materials):	Very high.
General Pluses:	Very low leach rate. Waste form is thermodynamically stable.
General Minuses:	Accepts waste after oxidation only. Extensive off-gas system required for volatiles. Unproven technology. Silicates form undesirable phases.

APPENDIX D

SOUTH DAKOTA DEPARTMENT OF HEALTH
LICENSING FORM FOR RADIOACTIVE MATERIAL

SOUTH DAKOTA STATE DEPARTMENT OF HEALTH
Joe Foss Office Building
Pierre, South Dakota 57501

Questionnaire relative to licensing of possessors/users of radioactive materials

1. *(a)* NAME AND STREET ADDRESS OF APPLICANT. (Institution, firm, hospital, person, etc. Include Zip Code.)

(b) STREET ADDRESS(ES) AT WHICH RADIOACTIVE MATERIAL WILL BE USED. (If different from 1 *(a)*. Include Zip Code.)

2. DEPARTMENT TO USE RADIOACTIVE MATERIAL.

3. PREVIOUS LICENSE NUMBER(S). (If this is an application for renewal of a license, please indicate and give number.)

4. INDIVIDUAL USER(S). (Name and title of individual(s) who will use or directly supervise use of radioactive materials. Give training and experience in Items 8 and 9.)

5. RADIATION PROTECTION OFFICER. (Name of person designated as radiation protection officer if other than individual user. Attach resume of his training and experience as in Items 8 and 9.)

Telephone number:

6. *(a)* RADIOACTIVE MATERIAL. (Elements and mass numbers of each.)

(b) CHEMICAL AND/OR PHYSICAL FORM AND MAXIMUM QUANTITY OF EACH CHEMICAL AND/OR PHYSICAL FORM THAT YOU WILL POSSESS AT ANY ONE TIME. (If sealed source(s), also state name of manufacturer, model number, number of sources and maximum activity per source.)

7. DESCRIBE PURPOSE FOR WHICH RADIOACTIVE MATERIAL WILL BE USED. (If radioactive material is in the form of sealed sources, include the make and model number of the storage container and/or device in which the source will be stored and/or used.)

(Continued on reverse side)

8. TRAINING OF EACH INDIVIDUAL NAMED IN ITEM 4 (Use supplemental sheets if necessary).

TYPE OF TRAINING	WHERE TRAINED	DURATION OF TRAINING	ON THE JOB (Circle answer)		FORMAL COURSE (Circle answer)	
Principles and practices of radiation protection			Yes	No	Yes	No
Radioactivity measurement standardization and monitoring techniques and instruments			Yes	No	Yes	No
Mathematics and calculations basic to the use and measurement of radioactivity			Yes	No	Yes	No
Biological effects of radiation			Yes	No	Yes	No

9. EXPERIENCE WITH RADIATION (Actual use of radioisotopes or equivalent experience).

ISOTOPE	MAXIMUM AMOUNT	WHERE EXPERIENCE WAS GAINED	DURATION OF EXPERIENCE	TYPE OF USE

10. RADIATION DETECTION INSTRUMENTS (Use supplemental sheets if necessary).

TYPE OF INSTRUMENTS (Include make and model number of each)	NUMBER AVAILABLE	RADIATION DETECTED	SENSITIVITY RANGE (mR/hr)	WINDOW THICKNESS (mg/cm^2)	USE (Monitoring, Surveying, Measuring)

11. METHOD, FREQUENCY, AND STANDARDS USED IN CALIBRATING INSTRUMENTS LISTED ABOVE.

12. FILM BADGES, DOSIMETERS, AND BIO-ASSAY PROCEDURES USED (For film badges, specify method of calibrating and processing, or name of supplier).

INFORMATION TO BE SUBMITTED ON ADDITIONAL SHEETS

13. FACILITIES AND EQUIPMENT. Describe laboratory facilities and remote handling equipment, storage containers, shielding, fume hoods, etc. Explanatory sketch of facility is attached (Circle answer). Yes No

14. RADIATION PROTECTION PROGRAM. Describe the radiation protection program including control measures. If application covers sealed sources, submit leak testing procedures where applicable, name, training, and experience of person to perform leak tests and arrangements for performing initial radiation survey, servicing, maintenance and repair of the source.

15. WASTE DISPOSAL. If a commercial waste disposal service is employed, specify name of company. Otherwise, submit detailed description of methods which will be used for disposing of radioactive wastes and estimates of the type and amount of activity involved.

CERTIFICATE

16 THE APPLICANT, AND ANY OFFICIAL EXECUTING THIS CERTIFICATE ON BEHALF OF THE APPLICANT NAMED IN ITEM 1, CERTIFY THAT THIS APPLICATION AND ALL INFORMATION CONTAINED HEREIN, INCLUDING ANY SUPPLEMENTS ATTACHED HERETO, IS TRUE AND CORRECT TO THE BEST OF OUR KNOWLEDGE AND BELIEF.

Applicant named in Item 1

Date _____ By _____

Title of certifying official authorized to act on behalf of the applicant

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TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. 908/6-82-009	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Disposal of Radium-Barium Sulfate Sludge From a Water Treatment Plant in Midland, South Dakota		5. REPORT DATE December, 1982 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Kimball, Connie and Orzynski, Steve		8. PERFORMING ORGANIZATION REPORT NO
9. PERFORMING ORGANIZATION NAME AND ADDRESS Fred C. Hart Associates, Inc. 1320 17th Street Denver, Colorado 80202		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-01-6008
12. SPONSORING AGENCY NAME AND ADDRESS U. S. Environmental Protection Agency, Region VIII 1860 Lincoln Street Denver, Colorado 80295		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The town of Midland, South Dakota has levels of radium-226 in its groundwater drinking water supply which exceed EPA drinking water standards. A newly-designed treatment plant will use barium chloride to precipitate out the radium. As a result, a radium-barium sulfate sludge will be produced.

The initial task of this report is to determine the degree of radioactivity of the sludge and to investigate the appropriate EPA, NRC and DOT guidelines which regulate the handling and disposal of this low-level radioactive waste. Hazards both to workers and intruders are assessed. The quantity and quality of the sludge are consequently projected and alternative disposal methods evaluated. Packaging and shipment to a licensed radioactive waste disposal site, co-disposal with uranium mill tailings, disposal at a state-operated site, and land disposal at the treatment plant are considered as alternatives. Various immobilization techniques, including bitumenization, polymeric solidification and concrete encapsulation are also investigated.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Radiation protection laws Radioactive water Radioactive waste processing Radioactive waste disposal Water treatment	Midland, South Dakota	

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